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MANUAL OF METHODS FOR FISH STOCK ASSESSMENT

Part III. SELECTIVITY OF FISHING GEAR

by
J. A. Pope

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1966

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MANUAL OF METHODS FOR FISH STOCK ASSESSMENT

PART III. SELECTIVITY OF FISHING GEAR

by

J.A. Pope
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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, January 1966

MR/33629

PREPARATION OF THIS PAPER

This forms an integral part of the FAO "Manual on Fish Stock Assessment". It is based on Part IV of ICES Co-operative Research Report (2) 1960. This is the report of the ICES Mesh Selection Working Group, 1959-1960, of which the author was convener. At the invitation of FAO he revised the relevant part of that publication, which dealt with the selectivity of trawls and seines, and added short sections on gill-nets and hooks. The history of this work is summarised in the Preface. The present provisional version has been reproduced primarily for use at FAO and associated training centres, in FAO field projects, and for limited distribution to specialists, on the basis of whose comments it is planned a revised edition will eventually be published in the official languages of FAO. The final revision will take into account experience in the use of the present version for training purposes, and will incorporate advances in this field of research.

We are indebted to the Literary Executor of the late Sir Ronald A. Fisher, F.R.S., Cambridge, to Dr. Frank Yates, F.R.S., Rothamsted, and to Messrs. Oliver and Boyd Ltd., Edinburgh, for permission to reprint Tables Nos. XI and XI.1 from their book "Statistical Tables for Biological, Agricultural, and Medical Research".

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Provisional edition of a manual part giving an account of purposes and methods of estimation of certain parameters in mathematical expressions employed in assessing fish stocks. Demonstrates applications of methods by examples and illustrations.

PREFACE

In December 1959 the International Council for the Exploration of the Sea (ICES) convened at Copenhagen a Mesh Selection Working Group composed of a number of scientists whose main task was to analyse and review the results of preceding mesh selection experiments, especially joint and international ones that had been sponsored by ICES, and to discuss methods of data analysis and experimental procedures in this field. At that meeting, and subsequently, FAO was associated with the activities of the working group through the participation of a staff member, Mr. E.F. Akyüz, as observer. A second meeting of the working group, with the author of this document as convener, took place in December 1960. At the 1960 meeting the standardization of experimental techniques was further discussed, and this led to the preparation of a document entitled "General considerations on trawl and seine mesh selection and its measurement". This was subsequently published in 1964 as Part IV of ICES Co-operative Research Report (2), entitled "Report of the Mesh Selection Working Group, 1959-1960".

Since its inception it was planned that the manual in the present series dealing with fish stock assessment methods would contain a major section on gear selectivity. Where adequate manuals or reviews were published or being prepared elsewhere, FAO's policy has been either to defer preparation of parts of manuals in its series of Manuals in Fisheries Science covering those subjects or to take full advantage of the existence of other texts in preparing the FAO volume. In certain instances an interim solution seemed to be desirable. Such was the case with the part of this same Manual dealing with marking experiments: the provisional version, for use pending the preparation of a complete new draft, consists of the combined printed texts of the report of an ICNAF Symposium on this subject and a relevant contribution to an ICES Symposium on the measurement of fish abundance, supplemented by a review prepared for an FAO/GFCM Training Centre and Seminar on sardine tagging. In the case of gear selectivity, it became apparent that with little modification the ICES publication could provide the basis for the part of the Manual of Methods for Fish Stock Assessment, at least in relation to the selectivity of trawls and seines. Accordingly, FAO invited Mr. Pope to make the necessary revision. In doing so the author considerably expanded and rearranged the text, retaining however most of the elements of the original, and also adding short sections on the selectivity of other types of gear, particularly gill nets and hooks.

Notwithstanding the work so far put into this text by many scientists it is still to be considered only as a draft to be revised on the basis of experience in its use, comments from other specialists, and advances in this field of research. It is being reproduced in the present provisional form primarily for use at training centres and in FAO field projects, and to facilitate comment by others.

The present manual part has been written essentially from the point of view of estimation of certain parameters in mathematical expressions employed in assessing fish stocks. Gear selectivity is, however, a subject of considerable interest to fisheries technologists and to economists concerned with aspects of the efficiency of fishing operations: it is hoped that the methods, considerations and results summarised here will be of some direct value to those groups of fisheries workers, as well as assisting them to understand the activities and objectives of the biologists studying the dynamics of fish stocks.

Sidney J. Holt
Chief, Biology Branch
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January, 1966

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MANUAL ON GEAR SELECTIVITY

by

J.A. Pope

1. INTRODUCTION AND SELECTION CURVE

1.1 Introduction

Chance plays a predominant part in the capture of fish from a natural population. If any one individual were as likely to be captured as any other, and if the capture of an individual were not dependent in any way on those already captured, the method of capture would be non-selective. Processes which cause a departure from this situation are defined as selective ones. It is a characteristic of most fishing operations that they are selective, with the result that the catch is not representative of the population as a whole in one or more of its aspects, and the effect of the method of fishing on the population is not uniform over all sub-divisions of the population. The selectivity of any method of capture depends on both the method employed and on the behaviour of the individuals in the population, that is, on factors both intrinsic and extrinsic to the process of capture, and on the interaction between these. (For further discussion see ICNAF/ICES/FAO (1960)).

Because of the wide employment of bottom trawls by countries with highly developed fisheries most of our present knowledge of selectivity relates to fishing gear of that type, but some data are available for other gears.

The inherent selectivity of otter trawls arises mainly from the ability of some fish to pass through the open meshes of the netting. Escape of fish through the meshes can take place in any part of the trawl but experimental evidence suggests that the most important area of escape is in the cod-end. So far only cod-end selectivity has been extensively and systematically studied and much more work is still necessary in order to assess quantitatively the nature and relative numbers of escapes from the various parts of the trawl and thereby confirm the present general opinion that the cod-end is the area most important in selection.

This part of the manual is devoted mainly to the techniques of studying cod-end selectivity and to a survey of present knowledge of this particular aspect of fishing gear selectivity.

1.2 The Mesh Selection Curve

The ability of a fish to escape through a mesh of a cod-end during fishing depends on its dimensions in relation to the opening of the mesh. For roundfish the relevant dimension is the maximum girth and this will be either the head girth or the maximum body girth at the time of capture. For flatfish the relevant dimension will be related to the breadth of the fish. These dimensions are highly positively correlated with the length of the fish and so the ability of a fish to escape may be regarded as being dependent on its length, although the dependence is not direct. Thus because of the ease with which fish lengths can usually be measured it is customary to relate selection directly to length rather than to any other dimension.

If all fish whose maximum girth was less than the mesh size passed through the net wall while all fish whose maximum girth was greater than the mesh size did not pass through, the selection of the fish in relation to girth would be "knife-edged": that is, either all fish of a certain size (as measured by girth in this case) would be retained by the net, or none of them. Selection, even in this idealised situation, would not be knife-edged in relation to fish size as measured by length, for not all fish of the same length have the same girth. Furthermore, in practice, most cod-ends, especially those which are braided by hand, contain a range of mesh sizes. These factors alone would result in a retention pattern exhibiting a gradation in probability of retention with girth and length. In addition, even a fish of a particular length having a girth less than that which could pass through even the smallest mesh will not with certainty escape. Thus almost all small fish will escape while large fish will certainly not

escape. Fish of intermediate sizes have probabilities of retention which increase steadily with increase in size. The relationship between the probability of retention and the length, when presented graphically, is termed the length selection curve. A typical length selection curve for the cod-end of an otter trawl is shown in Figure 1. The first aim in evaluating the selectivity of a cod-end is to estimate in a precise manner the length selection curve.

2. THE COVERED COD-END METHOD

Several experimental techniques have been employed for the study of mesh selection. The most widely used method is that known generally as the "covered cod-end" method. This involves attaching a cover of small mesh netting over the cod-end in such a way as to retain fish which escape from the cod-end itself. A cover may envelop the whole cod-end or may cover only a part of it.

The design and rigging of a cod-end cover require care to ensure that an unbiased picture of the retention is obtained. These points are discussed in section 2.2, but first we describe the method of recording and the manner of the initial presentation of the data from a covered cod-end experiment.

2.1 Recording and Initial Presentation of Data

The length measurements of the fish retained in the cod-end and of those taken in the cover must be separately recorded. If space aboard the experimental vessel permits two measuring teams to work simultaneously, this is probably best done by arranging for one team to deal with only the cod-end catch and the other with only the cover catch. Otherwise, one of the catches should be dealt with completely before proceeding to deal with the other. The length measurements of the two catches should subsequently be recorded on a suitably arranged working sheet such as that shown in Table I. A separate sheet should be used for each species from which selection data are obtainable. The data given in Table I relate to an actual set of observations for haddock (Melanogrammus aeglefinus) taken in a haul of one hour's duration. In column (1) is given a length scale with a suitably chosen grouping interval; one centimetre in this case. Columns (2) and (3) show the number of fish in each interval taken in the cod-end and cover respectively. The fourth column shows the percentages retained in each interval. The percentages need only be given to the nearest whole number and may easily be found with the aid of a slide-rule or a desk calculating machine. The figures in column (4) are shown plotted in Figure 1. It is useful to make as soon as possible a rough plot of the percentages retained in order to keep effective control over the experiment. Methods of fitting a curve to these points will be discussed in detail in section 2.3 and Appendix II.

2.2 The Design and Rigging of Covers

For the covered cod-end method to give a true measure of selectivity it is essential that the cover in no way affects the relative ability of fish of different sizes to escape from the cod-end. This method has frequently been criticised on the grounds that some fish which would normally escape from the cod-end if it were uncovered are prevented from doing so or are deterred by the presence of the cover. This effect is referred to as "masking".

The frequency distributions illustrated in Figures 2(a) and (b) show the length distributions (expressed as numbers per haul, 2(a), and as percentages, 2(b)) of catches of whiting (Merlangus merlangus) taken in the same cod-end in two sets of hauls made during the same period and on the same ground. In one set of hauls (8 in number) the cod-end was uncovered while in the other set (14 in number) the top half of the cod-end was covered by loosely fitting small mesh cotton netting in the manner shown in Figure 4.

Clearly, from Figure 2(a), the numbers taken per haul in the cod-end which was covered were, with one exception, greater at all sizes than the numbers taken with the uncovered cod-end. There was thus a general masking effect but it was greater for the smaller than for the larger fish. This is brought out in Figure 2(b) which shows that the percentage of fish of size less than 30 cm was consistently greater in the covered cod-end than in the uncovered one.

However, although there is evidence of masking in these data, masking has not always been found in such experiments. For instance, Parrish (1950) and Parrish and Pope (1951) found no evidence of masking for certain species in experiments carried out by them. The present consensus of opinion is that, provided adequate care is taken in designing the cover, unbiased estimates of selectivity can be obtained from the covered cod-end method. At the time of writing, however, no one particular type of cover has been designed which guarantees absence of masking, and therefore masking requires specific investigation in each experiment.

The attractiveness of the covered cod-end method lies in the fact that results are obtainable from single hauls and the actual escapes are observed. In practice the method is a relatively easy one and the analysis of the results is straightforward. For these reasons many attempts have been made to find cover designs which will reduce masking to a minimum.

Masking may be caused either directly by the cover lying against the cod-end, or the fish may perceive the cover, even if it is not lying against the cod-end and be deterred from attempting to escape. Again, the presence of some fish in the space between the cover and the cod-end may affect the escape of others. The flow of water through the cod-end may be greatly reduced if a cover is fitted and this too may reduce escapes.

The direction in which attempts at improving cover design and rigging have taken place has therefore been towards ensuring adequate space between the cod-end and cover in order thereby to reduce impedance to fish trying to escape and at the same time possibly improving water flow through the cod-end.

Cassie (1955) devised a method of suspending the cover in front of the cod-end from the batings by means of rope toggles so as to prevent it from lying against the cod-end during towing. Experiments carried out with a hemp cover of $2\frac{1}{2}$ in. mesh size suspended in this way showed improved escapement over earlier experiments with a cotton cover of mesh size $\frac{1}{2}$ in. laced directly on to the forward end of the cod-end.

Beverton (1958) found escapes of cod (Gadus morhua) from sisal and manila cod-ends were greater when using a cover with an extension bag than when using a similar cover with no extension bag.

Davis (1934) in his experiments used cane hoops to keep the cover well clear of the cod-end. In spite of this precaution, however, he found strong evidence of masking in some of his hauls. Boerema (1958), on the other hand, reported increased selection when hoops were used to support his cover which is illustrated in Figure 3. This had a mesh size of 30 mm and enveloped the whole cod-end while that used by Davis probably had a mesh size of 10 mm and covered only the top-side of the cod-end, the underside being blinded inside. Although the shooting and hauling of a small trawl fitted with hoops from a small vessel is not likely to present great difficulty the same is probably true with large trawls used on large ships.

An alternative to the use of attachments for keeping the cover clear of the cod-end has presented itself in recent years with the appearance on the market of naturally buoyant synthetic fibres such as those belonging to the polyethylene and polypropylene groups.

In a study of the effect on selection of covers made from cotton and Courlene, Pope (unpubl.) found that with the same cod-end the percentages of haddock escaping were higher when the Courlene cover was used than when the cotton cover was used. Masking thus occurs to a lesser degree, if at all, when a cover of naturally buoyant material is used.

The advantages of using a cover which envelops the whole cod-end, as against one which covers only the top-side, depends on whether fish escape through the underside or not, and this in turn is likely to depend on the construction of the gear and on the species being fished. Cieglewicz and Strzyzewski (1958) measured the number of escapes from the upper and lower halves of cod-ends of cotton, manila and rami from hauls made in the Baltic with the cod-ends covered by a whole cover divided into two compartments by horizontal sheets of netting. They found that more than 80% of cod which escaped did so through the upper halves in the cod-ends made of cotton and manila but that less than 30% of the escapement was through the upper half of the rami cod-end. This difference they attributed to the lightness of the rami cod-end in comparison with those of cotton and manila. This was borne out by the fact that when heavy chain was fixed to the lower side of the rami cod-end the percentage of the escapement which was from the upper side rose to 44%. A wide range of values for the percentage escaping from the upper and lower sides of cod-ends have been reported by other workers.

Several experiments have been undertaken by the Marine Laboratory, Aberdeen, to determine whether escapes increase when a whole cover is used in place of one which is fitted only to the top-side of the cod-end. In these experiments the cod-ends used with top-side covers have been

fitted with either under-side chafers on the outside or small mesh blinders inside. These experiments have generally, though not always, shown that the percentage escapes are higher when a whole cover is used than when the top half only of the cod-end is covered.

From these results it emerges that the following factors should be taken into consideration in devising a cover :

(a) the cover should be rigged so that, when fishing, it can lie away from the cod-end

(b) there should be ample space at the after-end of the cover to allow fish which have escaped from the cod-end to congregate without impeding further escapes

(c) the normal flow of water through the cod-end should be interfered with as little as possible

(d) wherever possible a whole cover should be used in preference to one which covers only the top-side of the cod-end and which thereby allows fish to escape naturally from the under-side.

To achieve (a) the cover should be very loose fitting and, if practical, be used with hoops or attached by means of a toggle arrangement. The material of the cover should be as light as possible while being as strong as necessary to avoid bursting when heavy catches of small fish are taken. The use of naturally buoyant material for the cover is recommended.

With regard to (b) the cover should extend some way beyond the cod-end (see Figure 4). General experience suggests that this extension should be not less than 4 ft and preferably 6 ft but the exact amount will be conditioned by the ability to get the cover with its catch aboard the vessel.

These experimental procedures will, to some extent, maintain the flow of water through the cod-end, and this may be improved by making the mesh size of the cover no smaller than is necessary to ensure that fish of the smallest size occasionally retained in the cod-end cannot escape through the cover. In practice it has been found that this requires the mesh size of the cover to be no less than half that of the cod-end.

With regard to (d) it may not always be sound practice to use a whole cover. On rough ground the under-side of a whole cover will be liable to damage. This can be partly, but not always completely, avoided by fitting under-side chafers, but the robustness of the chafers is largely limited by the strength of the cover netting. When a top cover only is fitted the under-side of the cod-end should be blinded by fitting small mesh netting inside the cod-end. This will, of course, reduce the effective escape area of the cod-end, but does ensure that all escaping fish enter the cover. In reducing the effective escape area the possibility of a downward bias on selection cannot be ruled out. On the other hand, if no under-side blinder is fitted, escapes may occur through the under-side and the amount of these may vary even under relatively uniform conditions thereby introducing a completely indeterminate factor.

Finally, whenever the covered cod-end method is employed to measure selectivity it is advisable to make some hauls with the cod-end uncovered so as to provide a reference set of data from which the existence of cover masking may be detected. This should be done in a properly planned way (see section 8).

2.3 Fitting the Length Selection Curve

The presentation of selectivity data from covered cod-end hauls in the form of a graph (see Figure 1) of the observed proportion, p, of fish in a specified length interval which are retained by the meshes, against ℓ, the size of fish in grouped length intervals, shows a gradual though generally irregular increase in p from zero at low values of ℓ to unity at high values of ℓ. In addition, selection curves have frequently been found to be symmetrical, or nearly symmetrical, about the value $p = 0.5$. The similarity between such a selection curve and the integrated form (ogive) of a symmetrical frequency distribution is obvious and was early noted

by Buchanan-Wollaston (1927) who suggested that the frequency distribution might be taken to be the normal (or Gaussian) distribution. Of course distributions other than the normal possess the property of symmetry about the median but the wide applicability of the normal distribution made it an attractive one to use as a form for the length selection curve, and indeed its use has been rationalized in terms of the "chance" nature of the selection process.

Other curves, specified without direct reference to any frequency distribution, may be postulated. Such a curve is the logistic which is very similar in shape to the normal ogive, though having quite a different mathematical expression.

The need to specify the curve in mathematical terms only arises where it is proposed to fit such a curve and this in turn may not be necessary if it is only intended to specify some aspects of the curve and not the curve as a whole.

It has become standard practice to specify a length selection curve in terms of the 50% retention length and the selection range. These quantities have the following definitions:

50% Retention Length (= 50% point) : The length of fish at which 50% are retained in the cod-end and 50% escape.

Selection Range : The range of length of fish between the 25% and 75% retention lengths.

It will be noted that the selection range is not defined in terms of the 0% and 100% retention lengths. These points are not easy to determine graphically and for some curves specified in precise mathematical terms (e.g. the normal ogive and logistic curves) have always the values $-\infty$ and $+\infty$.

2.3.1 Graphical Methods

The simplest and at present most widely used method of fitting a selection curve is to draw, by eye, a smooth curve passing as closely as possible through the observed points. Although practice brings with it a certain amount of skill in exercising correct judgment this method is subject to criticism on two counts. In the first place no two people are likely to draw exactly the same curve to a given set of points, nor even can the same person be sure of repeating the same curve in fitting twice to the same data. In the second place no estimate of the error of fitting is available. Nevertheless, the method is quick and may be recommended for a preliminary analysis.

Some simplification can be introduced into the fitting of the curve. If the true curve is assumed to have the sigmoid form of the normal ogive, then instead of plotting the proportion retained against length, the corresponding normal deviate may be plotted against length whereby the relationship is linearised and the fitting reduces to that of drawing a straight line. Alternatively, Tables of Probits, which are normal deviates with 5 added, may be used. Suitable tables are to be found in "Statistical Tables for Biological, Agricultural and Medical Research" (Fisher and Yates, 1963, Table IX) and elsewhere. For example, using the selection data in Table I, we find, from Fisher and Yates' table, the entry 3.1192 for a value of P = 3, this being the percentage escaping at a length of 19 cm. The normal deviate is, therefore, -1.8808 which may be rounded to -1.88. The transformed data are :

Length	18	19	20	21	22	23	24	25	26	27
Percentage	0	3	6	20	30	55	80	89	92	100
Normal Deviate	$-\infty$	-1.88	-1.55	-0.84	-0.52	0.13	0.84	1.23	1.41	$+\infty$

The normal deviates are shown plotted in Figure 5 with a straight line fitted by eye ignoring the points at $\pm\infty$. The 50% retention length read off the fitted line is 22.8 cm, this being the length corresponding to a normal deviate of zero. The 25% and 75% retention lengths correspond to normal deviates of -0.67 and +0.67 respectively and, from the graph, give the values 21.5 cm

and 24.1 cm. The selection range is, therefore, 2.6 cm. It is of course unnecessary to carry out the process of fitting and estimation with normal deviates, the unadjusted probits may be employed equally well. These values may be compared with those obtained from Figure 1 where the following values were obtained: 50% retention length = 22.9 cm; 25%, 75% retention lengths = 21.6 cm, 24.0 cm; selection range = 2.4 cm.

Special graph paper, called arithmetic probability paper, has been prepared in which the ordinate scale is graduated in terms of normal deviates. This obviates the necessity for a table of normal deviates.

If the curve is assumed to follow the logistic law rather than the normal, the curve is similarly transformed into linear form by plotting quantities called logits, against length. Special graph paper, called logistic paper, may be used for this purpose or alternatively tables of logits such as are found in Fisher and Yates' Tables (Table XI). Details are given in Appendix II.

No estimate of variance is available for a 50% retention length obtained graphically.

2.3.2 A Simple Numerical Method

50% points may be simply estimated by the method of moving averages. This method was used by Thompson (1947) to deal with dose-response data from biological assays. It consists of calculating moving-averages of the p's and l's and using linear interpolation in the resulting series to find the 50% point. Thus, if p_1, p_2 ..... are the proportions escaping at lengths l_1, l_2 ..... and if 3-point moving-averages are used, a new series of $\bar{p}$'s and $\bar{l}$'s are obtained thus :

$$\bar{p}_2 = (p_1 + p_2 + p_3)/3 \qquad \bar{l}_2 = (l_1 + l_2 + l_3)/3$$
$$\bar{p}_3 = (p_2 + p_3 + p_4)/3 \qquad \bar{l}_3 = (l_2 + l_3 + l_4)/3$$
$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

For the data of Table 1 we have

$$\bar{p}_2 = 0.03 \qquad \bar{l}_2 = 19$$
$$\bar{p}_3 = 0.10 \qquad \bar{l}_3 = 20$$
$$\bar{p}_4 = 0.19 \qquad \bar{l}_4 = 21$$
$$\bar{p}_5 = 0.35 \qquad \bar{l}_5 = 22$$
$$\bar{p}_6 = 0.55 \qquad \bar{l}_6 = 23$$
$$\bar{p}_7 = 0.75 \qquad \bar{l}_7 = 24$$
$$\bar{p}_8 = 0.87 \qquad \bar{l}_8 = 25$$
$$\bar{p}_9 = 0.94 \qquad \bar{l}_9 = 26$$

The 50% point lies between $\bar{l}_5$ and $\bar{l}_6$ and is, by linear interpolation, equal to $22 + (0.50-0.35)/(0.55-0.35) = 22 + 0.75$ cm $= 22.75$ cm.

In applying the moving-average method spans of length other than 3 units may be used. The use of spans of odd order is very convenient if the l-values are equally spaced, as will usually be the case, for then the values of $\bar{l}$ coincide with the original l's.

Although this method is suitable for estimating the 50% point of the length selection curve it should not be used for estimating any other percentage point.

If it is assumed that the number of escapes of fish of a given length follows the binomial distribution, an expression for the variance of the estimated 50% point (var ℓ_{50}) is available. When it is estimated by interpolating between the 3-point moving averages $\bar{p}_{i+1} < 0.50$ and $\bar{p}_{i+2} > 0.50$ it is given by

$$\text{var}(\ell_{50}) = \left\{ f^2 \frac{p_i q_i}{n_i - 1} + \frac{p_{i+1} q_{i+1}}{n_{i+1} - 1} + \frac{p_{i+2} q_{i+2}}{n_{i+2} - 1} + (1-f)^2 \frac{p_{i+3} q_{i+3}}{n_{i+3} - 1} \right\} \cdot \frac{d^2}{(p_i - p_{i+3})^2}$$

where p_i, p_{i+1}, ... are the observed proportions escaping at lengths ℓ_i, ℓ_{i+1}, ...; $q_i = 1-p_i, q_{i+1} = 1-p_{i+1}$, ...; n_i, n_{i+1}, ... are the total number of fish (cod-end plus cover) of lengths ℓ_i, ℓ_{i+1}, ...; d is the (common) length interval employed and

$$f = \frac{p_{i+1} + p_{i+2} + p_{i+3} - 1.50}{p_{i+3} - p_i}$$

This expression for var (ℓ_{50}) is an approximation, but is sufficiently accurate for practical purposes.

For the data from Table II we have

$$f = \frac{0.30 + 0.55 + 0.80 - 1.50}{0.80 - 0.20} = 0.25$$

$$\text{var}(\ell_{50}) = \left\{ (0.0625) \frac{(0.20)(0.80)}{82} + \frac{(0.30)(0.70)}{26} + \frac{(0.55)(0.45)}{21} + (0.5625) \frac{(0.80)(0.20)}{24} \right\} (0.36)$$

$$= 0.0659$$

$$\text{s.e.}(\ell_{50}) = \pm 0.26$$

The 95% confidence limits for ℓ_{50} are given with sufficient accuracy by $22.75 \pm (2)(0.26)$ = 22.2 cm, 23.3 cm.

2.3.3 Fitting the Whole Curve

No simple arithmetic procedures are available for providing unbiased estimates of percentage points other than the 50% point. Estimates of other points require the fitting of a curve of precise mathematical specification to the observations. The problem here is not the fitting of the curve but the choice of the curve. Buchanan-Wollaston (1927), for example, has suggested that a length selection curve might be graduated using the cumulative normal frequency distribution (normal ogive) although he did not fit such a curve to his data. The specification of this curve is

$$p_\ell = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\ell} e^{-\frac{1}{2}\sigma^2(\ell-\mu)^2} d\ell$$

An alternative symmetrical curve is provided by the logistic which is specified by

$$p_\ell = \frac{1}{1 + \exp\{-(\alpha + \beta\ell)\}}$$

A possible asymmetrical curve which might be employed is the Compertz curve

$$p_{\ell} = \exp\left[-\alpha.\exp(-\beta\ell)\right]$$

A detailed account of the fitting of the logistic curve is given in Appendix II.

3. THE ALTERNATE HAUL METHOD

The selection curve may be estimated from hauls in which the cod-end is uncovered (i.e. fished naturally). The length distribution of the fish over the total or major part of the selection range in the area where fishing takes place may be obtained by estimating the size distribution of the fish on the grounds from hauls using a cod-end of much smaller mesh size than that in the cod-end whose length selection curve is to be determined. (In practice it is sufficient that the cod-end of smaller mesh size selects fish only below the selection range of the experimental cod-end.) A direct comparison of this size distribution with that of the catches by the experimental cod-end then provides estimates of the percentage retention at each length by the experimental cod-end.

The most straightforward method and the one most free from experimental complications is that in which both the experimental cod-end and the standard (smaller meshed) cod-end are used with the same gear fished from the same ship. In the early applications of this method the cod-ends were used alternately and this gave rise to the name "alternate haul method" for this technique. The term is, however, generally used to cover not only that particular type of experimental method but also that in which the order of use of the cod-ends is randomised over the period as distinct from being used alternately or in which the cod-ends are used on different vessels fishing at the same time over the same ground. In the latter situation any difference in the fishing powers of the two vessels must be capable of evaluation.

The special merit of the alternate haul method is that it is free from any bias caused by the use of a cover. There are, however, several disadvantages in the method. Because of haul-to-haul variation in catches a much larger number of hauls are usually required to achieve the same precision of estimation as is given by the covered cod-end technique. A serious technical complication can be the change (usually an increase) in catching capacity of a net with increase in cod-end mesh size.

3.1 Estimating the Length Selection Curve

As an example of the fitting of a length selection curve to alternate haul data consider the figures given in Table II.

Column A gives the length frequency distribution of haddock taken in two one-hour hauls by a trawl with a cod-end of average mesh 35 mm. Column B gives the length frequency distribution for two one-hour hauls with a polypropylene cod-end of average mesh size 87 mm. These frequency distributions are shown graphically in Figure 6(a).

Taking the figures in column A as representing the length frequency distribution of fish on the ground, at least over the selection range of the polypropylene cod-end, the ratios B/A shown in column C will give the proportion at each length which escape through the polypropylene cod-end, i.e. the cod-end with the larger mesh. It will be observed, however, that from 31 cm upwards the larger meshed cod-end retained more fish than the smaller meshed cod-end. In part this will be due to sampling variation, but even when very large numbers of hauls are involved this feature is quite common in alternate haul experiments and it has been suggested that it may be due also to an increase in the fishing power of the gear arising from an increase in cod-end mesh size (Davis, 1934; Beverton and Holt, 1957).

Assuming here that proportionately more fish were taken at all sizes by the polypropylene cod-end, the necessary adjustment to the ratios B/A may be made by dividing by a factor expressing the catching efficiency of this cod-end relative to the cod-end with the smaller mesh. This factor may be estimated from the ratio of the catches above the selection range, in this case above 31 cm. The average of the ratios from 32 cm to 39 cm inclusive is 1.28 and the ratios of column C adjusted by dividing by 1.28 are shown in column D. The ratios above 39 cm have, in this case, been ignored since the numbers of fish taken above 39 cm are small and the ratios are very variable and quite different from those in the range 32-39 cm. An alternative way of making the adjustment is to use the ratio of the total numbers caught above the selection range, this being 682/531 = 1.28, which gives the same adjustment in this case. The adjusted ratios of column D are shown plotted in Figure 6(b). A free-hand curve drawn through the points gives an estimated 50% point of 30 cm. The more elaborate methods of estimating 50% points given in

Section 2.3.2 might be employed here but the arbitrariness of the method of arriving at the adjustment hardly makes this worthwhile. Other types of adjustment may be more appropriate in some cases. For a fuller account of this method reference should be made to Beverton and Holt (1957).

3.2 A Comparison of the Covered Cod-end and Alternate Haul Methods

The 50% point of the polypropylene cod-end referred to in the previous section was also estimated by the covered cod-end method and found to have a value of 28.7 cm. The alternate haul method thus gave a value some 4-5% higher than the covered cod-end method. It is a common feature of the alternate haul method that it gives higher estimates of 50% points than the covered cod-end method.

In view of the fact that the alternate haul method is a direct experimental parallel of what would happen in a commercial fishery when cod-end mesh sizes are changed, it is likely that estimated 50% points obtained by this method may be nearer the required figure than those given by the covered cod-end method, provided that an adequate number of hauls is made.

3.3 Variants of the Alternate Haul Method

The normal requirement for estimating selection curves by the alternate haul method is that the selection curves of the standard and experimental cod-ends be well separated so that their selection ranges do not overlap.

A method of estimating the 50% points of two cod-ends whose mesh sizes are so close that their selection curves do overlap has been given by Beverton and Holt (1957). Their method requires the assumption that the selection curves of both cod-ends are normal ogives with the same standard deviation.

A second variant of the alternate haul method is the "trouser trawl" method in which a divided type of trawl with two cod-ends is employed. In this way selectivity data for one or both cod-ends can be obtained from single hauls. There are, however, difficulties with this method mainly due to the technical problem of ensuring an equal or nearly equal flow of water through both legs of the trawl.

4. SELECTION BY GILL NETS

Little information on gill net selectivity has been published. It is known to differ from that of cod-ends in that the probability of capture increases to a maximum at a certain fish size and thereafter decreases.

Three lines of approach to estimating selection parameters of gill nets have been explored. In one of these the length frequency distributions of gill net catches are compared with the length-frequency distribution of the fish available for capture at the same place and time. This latter can sometimes be estimated by using another kind of gear such as a trawl or a purse-seine (Rollefsen, 1953) which is non-selective over the selection range of the gill net. A second approach is by way of theoretical considerations of the relation between mesh sizes and the girths of captured fish (Kipling, 1963; Treschev, 1963).

The third approach involves comparison of catches by gill nets of different mesh sizes, and requires assumptions about the shape of the length selection curve. Holt (1963) gives a solution for the case which he found to be applicable to several sets of data, in which the length selection curves have the shapes of normal frequency curves differing only in their central measures. Details of this method are given in Appendix II. Holt's method has also been applied by Olsen and Tjemsland (1961). Non-normal selection curves may also be encountered in practice. Thus Beverton has applied essentially the same method (but plotting the logarithms of catch ratios against the logarithms of fish length instead of against length itself) to a case, in which the selection curves are log-normal with dispersions increasing proportionally with mesh-size.

In reporting on its survey of available information on gill net selectivity, the joint ICNAF/ICES/FAO Scientific Meeting which considered the selectivity of fishing gear (1960) gave the following characteristics of the gear other than the mesh size as of seeming importance in gill net selectivity :

(1) elastic stretching of the net
(2) inelastic stretching of the net, including stretching of the knots
(3) hanging coefficients of the net (which govern the degree to which the meshes open)
(4) strength and flexibility of the twine
(5) visibility of the twine

Characteristics of the fish which are of possible importance were given as :

(i) its shape, compressibility of its body, and degree to which it is liable to be meshed at parts of the body other than pectoral area
(ii) its patterns of behaviour.

5. SELECTION BY HOOKS

Published experimental data on hook selectivity are scanty. The selection curve may in some cases be obtained from comparisons of catches by lines with those of some other gear such as of trawl (Saetersdal, 1957). Holt and Thomas (1957) found that Rollefsen's 1953 data for cod suggested a log-normal length selection curve for long-lines. Then, assuming log-normal selection curves, they applied the catch ratio method referred to in section 4 to McCracken's 1954 data for catches of haddock, and showed that for hooks of various sizes the central measure of the selection curve was proportional to a linear measure of hook-size. This is in accord with observations in several line fisheries that larger hooks and larger baits catch fewer small fish than smaller hooks and smaller baits. While present data do not permit a clear-cut separation of the independent effects of hook size and bait size, they do suggest that hook size may be the more important factor. The size of fish taken may also be influenced by the type of bait used.

There is little experience to draw upon in devising methods of research, although rigging the gear with alternate hooks of various sizes along a line seems a promising approach. It has been suggested that the following factors be taken into consideration in carrying out research on hook selectivity :

(a) difference in the attractiveness of baits
(b) length of time that baits stay on hook
(c) seasonal and diurnal variations in patterns of behaviour (e.g. many species do not eat, or eat less during spawning)
(d) availability of natural food
(e) relation between density of fish, spacing of hooks and competition for the hooks
(f) incidental catch of secondary species
(g) distances between hooks on line
(h) changes in hook shape with use
(i) probable loss of larger fish by breaking of lines or hooks
(j) differences in characteristics of stocks if gear must, during comparative fishing experiments, be tested on different grounds.

Many problems encountered in comparing and evaluating the results of various experiments arise from the lack of accurate descriptions of hooks and from the inadequacy of classification systems. Detailed descriptions of the shapes and sizes of the hooks used should be made and illustrations given. With present knowledge the relative importance of the various measurable characteristics of hooks in selecting sizes of fish cannot be stated, but the outside dimension across the back and shank of the hook as well as the length of a line drawn at right angles to the shank from the back to the shank are important, as also is the twist of the shank.

6. SELECTION FACTORS

The effect of increasing the mesh size of a cod-end is to increase the percentage escapes at each length. Surveys of existing selectivity data have shown that, in general, over a wide range of cod-end mesh sizes the relation between the 50% retention length and the mesh size is approximately linear. Empirical relationships for several species are given by Jensen (1949) based on the data available at that time. Summaries of data for haddock and redfish (Sebastes) are also provided by Clark (1957a; 1958).

Where sufficient data have been collected to determine a relationship it has been found, in almost all cases, that the 50% retention length is sufficiently nearly proportional to cod-end mesh size for a proportional relationship to be applied in practice. The constant of proportionality has been termed the selection factor: thus

$$\text{selection factor (s.f.)} = \frac{\text{50\% retention length}}{\text{mesh size}}$$

where both quantities on the right are in the same units of measurement. The selection factor is thus a dimensionless quantity, its value varying with the species of fish and also with the cod-end material (see Section 9.1). Selection factors obtained from experiments in North Atlantic waters have been found to lie mostly between 2.0 and 5.0.

Clark (1957b), in experiments on the selectivity of silver hake (Merluccius bilinearis) found quite large differences in the selection factors for cod-ends of the same material but of different mesh sizes; results which he took as indicating that it may not be sufficiently accurate in all cases to regard the 50% retention length as directly proportional to the mesh size for all species. Although no relationship between selection factors and mesh size has been reported by other workers, it is advisable, before employing selection factors for the description of cod-end selectivity to test whether they vary with mesh size.

An exact definition of mesh size is also required.

7. MESH MEASUREMENT

In theory, one would expect escapement to be related to the size of the meshes of the cod-end as they configurate under fishing conditions. However, at present, little is known about the shape of meshes during fishing. Consequently the mesh size is measured according to an arbitrary standard, the dimension taken being the distance between opposite knots of the mesh. This dimension is clearly related to the area of the lumen of the mesh during fishing. The measurement recorded for this distance is very much dependent on the pressure applied to the bars of the mesh. Consequently the pressure applied must be specified and standardised for comparative purposes.

Two major groups of mesh measuring devices have been used. They are :

(a) flat, wedge-shaped pieces of metal which are pushed by hand into the meshes at right angles to the join of opposite knots. These may or may not be equipped with a means of measuring and controlling the pressure applied in inserting the gauge. Those without a pressure regulating device are clearly of little use for accurate measurement.

(b) gauges which exert a longitudinal force between opposite knots of the mesh, i.e. a force along the direction of the join of opposite knots. A wide variety of gauges of this type have been designed. All incorporate a means of controlling and/or standardising the pressure exerted during measuring.

Several descriptions of mesh measuring gauges are to be found in the literature and reference should be made to Parrish, Jones and Pope (1956), v. Brandt and Bohl (1959), Strzyzewski and Zaucha (1957), Roessingh (1961), Parrish and Pope (1961), Bohl and Nomura (1961), and to Westhoff, Pope and Beverton (1962).

The conclusion from experiments with different gauges is that greater accuracy and consistency of measurement is obtained with longitudinal pressure gauges than with wedge-shaped gauges, even when the latter are fitted with pressure controlling mechanisms.

The addition of a stopping device on longitudinal pressure gauges to ensure that the pressure applied in obtaining the measurement cannot exceed a certain previously defined value has also been generally recommended.

Whilst a large measure of agreement has been reached on the correct pressure to apply in measuring the meshes of cod-ends of certain materials (namely, double manila, double hemp, double cotton, thick single manila), the pressure chosen has been arrived at mainly on the subjective grounds of requiring the bars of the meshes to be fully straightened but not stretched elastically nor so that the knots are tightened to a degree in excess of that which occurs in fishing. For the cod-end materials mentioned above the agreed pressure in European scientific work is 4 kg.

In practice the meshes of a cod-end will vary in size either due to the unevenness of braiding, especially if this is done by hand, or due to differential pressures being exerted over the cod-end when in use. When relating 50% retention lengths to mesh size, therefore, it is necessary to work with the average mesh size. The number of meshes to be measured in order to arrive at a sufficiently accurate estimate of the average mesh size will depend on the degree of variation in mesh size. For any given cod-end this can only be determined by measurement, although experience is likely to indicate that the degree of variation in cod-ends of the same material and braiding from the same source is sufficiently constant to enable, in time, the minimum number of meshes to be stated in advance. The accuracy of the mean mesh size can be evaluated in the usual way from its standard error.

Since the minimum number of meshes to be measured will normally be considerably less than the total number of meshes in the cod-end, the question naturally arises as to where in the cod-end the measurements should be taken. This should be in the area where the majority of escapes take place. Beverton (1963), v. Brandt (1960), Clark (1957c) and Cieglewicz and Strzyzewski (1958) have found that most fish escape through the after-part of the cod-end and therefore more

meshes should be measured in this area than in the forward part of the cod-end if there is a trend in mesh size along the cod-end. As a routine the meshes measured should be located on the top-side in a line running parallel to the long axis and starting from the after-end of the cod-end some three to five rows from the cod-line. Measurements should be recorded serially to enable any fore-aft trend to be detected. The line should not be located near the selvedges and meshes near or adjacent to strengthening ropes and lacings should not be measured.

Cod-end measurements should be made immediately after every haul while the cod-end is still wet. The number of meshes to be measured should not be fixed arbitrarily, because the minimum number to be measured depends on the desired accuracy of the average and on the standard deviation of the mesh size which will vary with cod-end construction and usage. It will usually be necessary that the mean mesh size be determined with an error of not more than 2%. To this end, if the observed 95% range of meshes is 20 mm and the average required to within 2 mm of the true value, measurement of about 25 meshes will usually be sufficient. If the number of meshes in one line is not sufficient a complete second line should be measured.

In quoting mesh sizes in scientific reports the number of measurements and the standard error of the mean size should be included as well as the average mesh size and range.

8. THE PLANNING OF EXPERIMENTS

One of the main advantages of the covered cod-end technique for measuring cod-end selectivity is that an estimate of the length selection curve is obtainable from a single haul. However, single hauls are normally subject to quite large variability so that several hauls will usually be necessary in order to provide a sufficiently accurate estimate of the average length selection curve.

In the course of a covered haul experiment it is advisable to make several hauls with the cod-end uncovered to test whether masking is occurring. In addition the experimenter may also wish to compare the length selection curves of several cod-ends or of several different fishing nets during the experimental period. When several different gears or variations of the same gear are to be used the order of making the hauls has to be decided. If experimental conditions are at all likely to vary during the period, it is essential that any differences detected in the comparisons be attributable to differences in the gear and not be indistinguishable from differences due to external factors which have not been controlled or which cannot be controlled.

While it is necessary to make estimates of differences from results obtained under as uniform conditions as possible it is also very desirable that comparisons should cover a wide range of practical conditions in order to provide for a wide applicability of the conclusions from the experiment.

Both these requirements can be met by dividing up the whole time available into periods within which experimental conditions are kept (or, if they cannot be controlled, are likely to be) as uniform as possible, making changes which result in (or are likely to result in) changes in experimental conditions only at the end of each experimental period.

For instance, if the length selection curve of a cod-end is to be determined by the covered cod-end method and simultaneously the effect of the cover on escapes is to be assessed, hauls with and without a cover should be suitably interspersed over the time available rather than making all the early hauls without a cover and all the later ones with a cover or vice versa. The simplest plan in this case would be to make fishing conditions on each day as uniform as possible (for example, by fishing on the same ground throughout a day, by keeping the rig of the gear the same throughout a day, etc.) and to make both covered and uncovered hauls each day. The fishing ground may be changed and variations in the rig introduced, if desired, from day to day. Even within each day conditions are unlikely to remain exactly uniform and in order to avoid any bias in each day's comparisons the order of making the covered and uncovered hauls should be determined by a random selection process. In this way the order of making the hauls will be determined at the outset of the experiment strictly in accordance with the rules of chance and not in any other way, such as, for instance, on the basis of results so far obtained. For details of the principle of randomisation see Fisher (1949), Cox (1958). (See also Pope, 1963).

One of the functions of randomisation is to afford protection against any disturbances which may occur and which may or may not be serious if they do occur. Randomisation also provides a basis on which strict statistical tests of significance of experimental differences may be carried out.

In some experimental situations definite trends in experimental conditions may seem likely. Thus, in the course of a day's fishing it may be expected that there will be a trend in abundance of fish or in species composition due, for example, to daily migrations off or on to the ground, or a trend in vulnerability due, for example, to changes in light intensity in the water. Either of these conditions may be thought likely to influence the experimental results in a way which, if not taken into account, might invalidate the conclusions to be drawn. It would then seem more reasonable to distribute the hauls with the different gears more evenly over the period than might be the case if the order was randomised in an unrestricted way, so that there is no chance that all hauls of one type are taken at the same time each day. Systematisation of order can be introduced while still retaining the necessary randomisation to ensure validity of the statistical appraisal of the results. This may be done by employing an experimental design based on the Latin Square which provides for each gear being used at a different time each day but, over the experimental period, is used at all times of the day. The method of randomising order of hauls subject to this type of restriction is to be found in, for example, Fisher and Yates (1963).

The Latin Square design requires that the number of days be an exact multiple of the number of different gears or cod-end and cover combinations, etc., used in the experiment. This usually raises no difficulty but, should there be more gears, etc., than days, alternative designs are available.

It is always advisable to take the trouble to randomise even when it is not expected that there will be any serious bias arising from failure to randomise.

8.1 The Combination of Estimates

When several estimates of say the 50% retention length, or selection factor, for a particular species of fish and a particular cod-end have been obtained from a series of hauls in one experiment it will often be desirable to quote a single average value. Two possible forms of average may be considered. If x_1, x_2, ..., x_n are n estimates they may be combined to give a simple unweighted mean

$$\bar{x} = (x_1+x_2+ \ldots + x_n)/n$$

or a weighted mean

$$\bar{x}_w = (w_1x_1+ w_2x_2 + \ldots + w_nx_n)/(w_1+ w_2 + \ldots + w_n)$$

where w_1, w_2, ..., w_n are weighting factors.

If the weighting factors are chosen to be proportional to the reciprocals of the variances of the estimates then $\bar{x}_w$ has a smaller variance than any other average. If the variances of $x_1, x_2, \ldots, x_n$ are all equal then $\bar{x}_w$ will be equal to $\bar{x}$ and the variance of $\bar{x}$ will be equal to the variance of $\bar{x}_w$.

By choosing the w_i's to be inversely proportional to the variances of the x_i's, more weight is given to the more accurate estimates. For $\bar{x}_w$ to be a valid average the weighting factors must not be associated with the estimates. For example, if the less accurate hauls tend to give lower selection factors a weighted mean might be misleading.

Again, the range of the variances of the estimates may be large, giving the impression of very great accuracy in some of the estimates and very poor accuracy in others which may not always be satisfactory or realistic. The variance formula given in Section 2.3.2 is dependent on the number of fish caught and where this is small the variance of the estimated 50% point may be considerably larger even with smaller deviations from a smooth selection curve than that from a very large haul giving greater deviations. To overcome this an upper limit may be set to the weighting factors, any weighting factor exceeding this limit being replaced by this limiting value.

When combining estimates of 50% retention lengths obtained by the moving average method explained in Section 2.3.2 the true weighting factors are not given by the reciprocals of the variances calculated using the expression given there for var(ℓ_{50}). This expression is only a large sample approximation. While approximate weighting factors may be calculated using these approximate variances, the minimum variance property of the weighted mean is lost by this procedure. However, the use of approximate weighting factors may often be better than no weighting at all.

In some instances it may be impossible to derive selection curves for any, or most, of the individual hauls, due to low catches. Such data may, however, yield a selection curve if the individual cod-end and cover catches, on separate summation, give sufficient numbers of fish for the reliable determination of percentage retentions. If all hauls in an experiment are summed in this way no estimates of the variability in the parameters of the curve are available. Therefore, when individual hauls cannot provide selection curves they should, if possible, be summed in groups to provide as many selection curves as possible. The extent of the sampling error in, say, the estimated 50% points may then be gauged from the separate values, with or without weighting as appropriate.

Summations of this sort should only be attempted when it seems certain that the population of fish being sampled has not changed during the course of the experiment.

When combining average values of 50% retention length or selection factor from different experiments the safest general rule is to employ an unweighted mean of the average values for the different experiments and set confidence limits using the variance of the experiment averages. This is recommended because it will be the case, more often than not, that results from different experiments will be less homogeneous than results from the same experiment.

8.2 Practical Considerations in Experimentation

Improvement in the accuracy of estimation of a length selection curve can only be gained by increasing the number of hauls. For this reason it is advisable to make as many hauls as possible during the experimental period. Although it is advisable in early stages of experimentation to tow for the same length of time as is done in relevant commercial practice, tows of shorter duration may with considerable advantage be used provided this does not affect the results in any way. (See Section 9.2).

If new, unused cod-ends are to be used in an experiment they should first be stretched and immersed in sea water to reduce initial mesh size changes. This can be achieved by making a few hauls with them, measuring the mesh size each time, until the average mesh size and the variance change little.

If the experimental design requires frequent changes of cod-end this may be considerably speeded up by using a row of plastic rings on both cod-end and net and lacing these rows of rings together. This method is very frequently used in experimental work and on occasions by some commercial fishermen. The method has been described by v. Brandt, Kreuzer and Messtorff (1958).

All relevant information should be noted in detail during the experiment. (See Appendix I).

In addition to recording the length measurements of the cod-end and cover catches of the species whose length selection curve is being investigated it is advisable, if time permits, to record also the lengths of all other species taken in the hauls. This may permit further analyses of the data not contemplated at the time the experiment is planned or carried out. When catches are very heavy there may be insufficient time for dealing with each species in full, and sampling may have to be introduced. Provided sampling is undertaken with care there is no reason why unbiased estimates of length frequency distributions or other catch data should not be obtained. If the major species is taken in very large quantities over its entire size range the simplest procedure is to take a uniform fraction of the fish over the whole range. If, on the other hand, large numbers are taken in the size ranges outside the selection range but not within it, it is better to confine the sampling to the sizes outside the selection range.

The most efficient sampling procedure will vary according to conditions and requirements and so no scheme optimum under all circumstances can be stated. Ideally, strictly valid statistical sampling entails the random selection (in the probability sense) of fish, a requirement which can rarely be met under working conditions. However, something closely approximating to this can usually be attained with little difficulty. An account of one form of sampling which has been found convenient and reliable in practice is given by Pope (1963). Whatever form of sampling is used it is necessary first to assess its accuracy for the purpose. This can usually be done by making one or two small-scale experiments. A manual of sampling methods for fisheries biology has been prepared by Gulland (1962), in which the methods of developing a good sampling system for the quantities of major interest in fisheries biological research is outlined in great detail.

Besides noting fish lengths it is also advisable to record the numbers of all species taken and the weights of the total cod-end and cover catches separately. The size of the catch may have an effect on the length selection pattern. (See Section 9.2).

It has already been pointed out in sub-section 1.2 that the dimension of a fish which determines whether it can or cannot escape from a cod-end is not directly its length but its maximum girth. Selection factors for a given mesh size and different populations of the same fish species may therefore vary if different girth-length relationships are exhibited by the

different populations. Even within the same population there may be seasonal or longer term changes in the girth-length relationship associated with the stage of maturity, with variations in feeding rate, with different growth patterns in different year classes, etc.

In the case of roundfish the girth may be measured at two points along the body, either at the point of maximum head girth which occurs in the region of the pterotic bone or at the point of maximum body girth which is near the position of the anal vent. The body girth may be measured as the constricted body girth after the manner of Margetts (1957) who gives body-girth/length relationships for North Sea whiting and cod and an interesting discussion on the application of such relationships to mesh selection. Head-girth/length relationships for North Sea haddock and whiting have been published by Lucas et al. (1954) who also discuss the application to mesh selection.

Although the few data available on whiting (Lucas et al., Margetts) indicate that maximum natural body girth is approximately 2-3 cm greater than head girth at the same total length, at the present time it is not possible to state which girth dimension should be selected for study in relation to mesh selection. The head girth is probably the easier to measure and is likely to be less subject to measurer's error than the body girth. It is recommended that in initial investigations measurements should be made of both head and body girth until sufficient data have been accumulated to provide accurate estimates of relationships for different populations and different periods of time. If necessary the air bladder should be punctured prior to measuring body girth.

9. FACTORS OTHER THAN MESH SIZE AFFECTING COD-END SELECTION

The accumulation of a large amount of cod-end selectivity data for both trawls and seines has brought to light the existence of other factors besides mesh size which affect cod-end selection.

One of the most important of these is the material from which the cod-end is made. Others include the size and weight of the catch, the duration of the haul and the speed at which the gear is towed.

9.1 Cod-end Material

A difference in the selective properties of different materials was observed when comparisons were made of results for manila trawl cod-ends and cotton seine-net cod-ends. (Graham, 1954; Lucas et al., 1954). Boerema (1954) also found a difference in the selection of hemp and manila trawl cod-ends.

These findings led to what is termed the "light trawl" problem, a loose term used in discussion of the observation that cod-ends of light material (cotton, hemp, thin single manila) have higher selection factors than cod-ends made of heavy or double manila and sisal.

Since 1954 considerable attention has been paid to the study of cod-end material in relation to mesh selection. Great impetus has been given to this work by the rapid expansion in the use of synthetic fibres for fishing twine manufacture.

In addition to cotton and hemp it has been found that cod-ends made from polyamide and polyester fibres also have relatively higher selection factors (Margetts, 1956; v. Brandt, 1956; Boerema, 1958; Cieglewicz and Strzyzewski, 1959; Margetts et al., 1964; Pope et al., 1964).

This work has been paralleled by scientific studies of the physical properties of twine material (v. Brandt, 1957) and the devising of various methods of measuring properties such as twine strength, flexibility and extensibility. (A compilation of property test methods is at the time of writing being prepared by v. Brandt.) These studies have shown quite clearly that the physical properties of twine depend not only on the material from which the twine is made but also to a very large extent on the construction of the twine (whether twisted, plaited, monofilament, etc.). As yet no single property of the material or twine has been identified as the chief factor in causing differential selectivity as might be expected, since selectivity depends also on the shape and tension in the net while it is fishing.

9.2 Catch Size, Duration and Speed of Tow

Several investigators have found an association between catch size and selection, the selection factor tending to be lower when catches are high. Thus Clark et al. (1958) report that in the north-west Atlantic area the 50% point for haddock may decrease by as much as 5 cm from light to heavy catches, but they do not specify the actual range of catch sizes over which this decrease has been found.

Margetts et al. (1964) also found, in some instances, lower selection factors for cod with large catches, using the covered cod-end technique. Thus, for example, in one series of hauls dealt with by them they found selection factors for this species of 3.5, 3.0 and 2.8 from hauls with average catches of 340 kg, 860 kg and 1800 kg respectively. On the other hand these authors found no such relation in data from alternate haul experiments.

Other writers who have found evidence of lower selection factors for hauls with large catches are Beverton (1963) and v. Brandt (1960).

This reduction in selection factor may be due to changes in mesh shape, the blocking of meshes or changes in fish behaviour with large catches. The effect, however, appears to have been detected only in covered cod-end hauls and may be partly or wholly due to the presence of a cover. The subject merits further careful study in view of its important bearing on the appli-

cation of the results of selectivity experiments to commercial fisheries as the level of commercial trawl catches is generally higher than that in selectivity experiments.

There is some evidence that selection factors increase with increasing duration of tow in trawl hauls (Clark, 1957b; Beverton, 1959). This could be explained by the fact that most fish make not one but repeated attempts at escape, the increase in towing time thereby providing a greater chance of escape. This will, however, generally be accompanied by an increase in size of catch and these two factors tend to act in opposing directions. In analysing the results of experiments designed to test the effect of tow duration on selection appropriate care must therefore be taken to eliminate from the comparisons any effect of variations in catch size.

Saetersdal (1958, 1960) found a decrease in selection factor with increasing towing speed in the case of Arctic cod. In conducting selectivity experiments the results of which are to be applied to specific commercial fisheries, it is therefore recommended that the speed of tow should be the same as in the commercial fishery.

APPENDIX I

THE PRESENTATION OF RESULTS

When reporting the results of selection experiments it is essential that all relevant data relating to the methods employed in collecting and analysing the results be clearly recorded in a tabular form which will be readily understood by other workers. The following list of information which is essential in all reporting is based on the recommendations of the ICES Mesh Selection Working Party (1964), which was later amended and revised by the ICES Comparative Fishing Committee, at its 52nd meeting, 1964 (ICES 1965).

As it stands, the following list meets also the case in which data from several hauls are combined to give a simple selection result. The most appropriate way of grouping hauls must, of course, be left to the discretion of the scientist.

This list is not an exhaustive one, and any special circumstances applying to the tests, or supplementary information such as girth measurements, must be mentioned. If results for individual hauls are to be given, the presentation can be adapted accordingly.

ITEM

1. Ship
   Size (length or gross tonnage) of the vessel employed and the engine horse-power should be quoted.

2. Gear
   Full description of the gear under consideration should be given. This should include the more important dimensions (e.g. ground rope dimension of trawl, size of nets for gill nets, etc.) and the material used in its construction.

3. Date

4. Time
   In view of the substantial differences of selectivity in day-light and darkness, the time of day should be given and, when possible, light meter readings at the depth at which the gear is operating should be taken and reported. The weather conditions prevailing during the experiments should also be mentioned with particular reference to the state of the sea.

5. Locality
   The fishing grounds should be specified and details given of the nature of the bottom.

6. Depth range

7. Cod-end material
   (Including runnage, braiding, treatment, Tex. no.)

8. Type of mesh gauge
   The recommended gauge for the North Atlantic is the ICES gauge which operates at a pressure of 4 kg. (Westhoff, Pope, Beverton, 1962). If another type of gauge is employed it must be described and the pressure at which it operates should be exactly specified.

9. Mesh size ..... Mean : to nearest mm
   Range : in mm
   S.E. of Mean : to nearest 0.1 mm
   No. of measurements

In gill net experiments the hanging coefficients of the nets should be stated. In reporting experiments with hooks, the dimensions of the hooks and their spacing along the lines should be stated.

10. Experimental method
A description of the experimental method employed should be given including details of experimental design. The total number of fishing operations made should be stated.

11. Dimensions, material and mesh
Size of cover.

12. Species

13. 50% retention length ..... to nearest mm

14. Selection factor ..... S.F. to 1 decimal place
(S.E. of S.F. to 2 decimal places)

It is intended that the S.E. of the mean selection factor should be calculated from selection factors obtained from individual hauls. If the data are insufficient, the S.E. cannot be given.

15. 25 - 75% selection range ..... to nearest mm

16. Number of fish of the species studied in selection range, in cod-end and cover separately.

17. Average weight per haul of all fish species (including that studied) in cod-end and cover separately ..... in kg.
If there are marked variations in the catch composition of the hauls being summarized, it is advised that the main composition of each should be stated separately.) *

18. Quantity and composition of other catch (including weed, sponge, crustacea, etc.) ..... in kg.
in kg.

* same applies

19. Number of hauls

20. Average duration of haul ..... hours and minutes

21. Towing speed (speed through water) ..... knots

APPENDIX II

FITTING LENGTH SELECTION CURVES

1. Fitting the Logistic Curve

Several methods of fitting a curve to the plot of proportion of fish retained by the cod-end in a covered cod-end experiment against length are described in Section 2. These methods are :

a) drawing a curve by eye
b) drawing a straight line by eye after transforming the proportions to normal deviates or probits
c) the use of unweighted moving averages of the data.

Method a) has the disadvantages of being entirely subjective and of providing no estimate of the accuracy of the fitted curve. Method b) as described in section 2.3.1 has the same disadvantages, its superiority over a) being that straight lines are generally easier to draw than curves. Method c) provides an unbiased estimate of the 50% point. It does, however, permit the evaluation of the error of the estimated 50% point.

In Section 2.3.3 possible mathematical specifications for a length selection curve are given. Both the integrated normal and the logistic curves have been employed in practice and found to provide satisfactory fits to selection data. There is little difference between their shapes and there are no theoretical reasons for preferring one form to the other.

In this section the procedures to be followed in fitting the logistic curve by maximum likelihood are given. Essentially, the procedure is to transform the selection curve into a straight line by replacing the observed proportions retained at each length (p) by quantities called logits ($L = \ell n\ p/1-p$). Since the sampling variation of a proportion is not the same for all proportions it is necessary when fitting the line exactly to employ different weighting coefficients for different values of L.

First, a provisional line is fitted by eye; then adjustments, using the weighting coefficients, to the slope and intercept of this line are calculated. If necessary the adjusted line may be used to provide further adjustments.

As an illustration a logistic curve has been fitted to the data given in the first three columns of Table II.1 in which the proportions retained relate to length intervals of 2 cm. The calculations are set out in columns (5) - (11) of Table II.1.

Fitting the logistic equation by maximum likelihood is made much easier by using tables of the logit transformation (see e.g. Fisher and Yates (1963), Table XI). One such is given as Table II.6.

Table II.1 is obtained as follows :

Columns (1)-(4) These are the basic data.

Column (5) In this column the logits corresponding to the observed values of p in column (4) are entered. Alternatively, the data as percentages may be plotted on logistic graph paper and the entries in column (5) omitted.

Column (6) The logits are plotted on ordinary graph paper and the best fitting line drawn by eye (Figure II.1). Alternatively, a line may be drawn by eye to the percentage points on the logistic graph paper. The expected logits, L, are read from this line and entered in column (6).

Column (7) The proportions, P, corresponding to the values of L in column (6) are read from Table II.6 and entered in column (7).

Column (8) The weights, w, corresponding to the values of L in column (6) are read from Table II.7 (Fisher and Yates' Table XI.1) and entered in column (8).

Columns (9)-(11) The values of nw, nwx and nP are found and entered in columns (9), (10) and (11).

The quantities shown below Table II.1 are next found.

The equation of the original line drawn by eye is

$$\frac{L + 0.82}{x - 23.5} = \frac{1.20 + 0.82}{31.5 - 23.5}$$

or $$L = -6.75 + 0.2525x$$

The provisional values for the slope and intercept are thus 0.2525 and -6.75 respectively. The adjustments, given below Table II.1, are -0.0087 and +0.24 so that the second estimates of those parameters are

$$b = 0.2525 - 0.0087 = 0.2438$$

$$a = -6.75 + 0.24 = -6.51$$

and the equation of the adjusted line is

$$L_1 = -6.51 + 0.2438x \qquad \text{(II.03)}$$

By putting $x = 23.5, 25.5, \ldots, 31.5$ in equation (II.03) a new set of expected logits (L_1) are obtained. These may be used in a second cycle of calculations to provide further corrections to the values of the slope and intercept, but this will not usually be necessary.

After transforming the values of L_1 back to proportions P_1, the expected number of fish retained in each length group can be estimated by multiplying each P_1 by the total number of fish in the appropriate group. The product values nP_1 may be compared with the actual number of fish retained (r). If r and nP_1 differ appreciably and in a systematic way, the validity of the logistic curve as an adequate representation of the selection curve is questionable. If the deviations, though large, are not systematic, the hypothesis of linearity of the transformed relationship may be accepted, but, in this case, all estimated variances are too small. The significance of the deviations of r from their expectations nP_1 may be tested by calculating the quantity $(r - nP_1)^2/nP_1(1 - P_1)$ for each class interval and summing the values obtained. This sum

$$X^2 = \sum \frac{(r - nP_1)^2}{nP_1(1 - P_1)} \qquad \text{(II.04)}$$

is approximately distributed as a χ^2 variate with degrees of freedom (f, say) equal to two fewer than the number of length intervals employed in the analysis. Should the value of nP_1 in any class be less than 5 the χ^2 approximation may be adversely affected and the data for this class should be combined with those for the neighbouring class or classes to give a value of nP_1 for the combined classes greater than 5. This is not a hard-and-fast rule (Cochran, 1936). The modified value of X^2 thus obtained may then be tested as a χ^2, the degrees of freedom being two fewer than the final number of classes involved in calculating X^2.

The calculation of X^2 for the data given in Table II.1 is laid out in Table II.2. The values of L_1 given in column (4) have been obtained from equation (II.03) and P_1 from Table II.6 (Fisher and Yates' Table XI). The rest of Table II.2 is self-explanatory. The value of X^2 obtained, 1.156, is approximately distributed as χ^2 with 3 degrees of freedom. Reference to a table of the percentage points of the χ^2 distribution shows that this value is not significantly large and so the line (II.03) may be regarded as fitting the observed data satisfactorily.

From equation (II.03) an estimate of the 50% point of the selection curve is obtained by placing L equal to zero and solving for x. This gives

$$x_{50} = \frac{6.51}{0.2438} = 26.70 \text{ cm}$$

An adequate approximation to the variance of this estimate is

$$\text{var}(x_{50}) = \frac{1}{b^2}\left\{\frac{1}{A} + \frac{(x_{50} - \bar{x})^2}{S(nwx^2)}\right\} \qquad \text{(II.05)}$$

where $\bar{x} = B/A$.

Inserting the appropriate values in (II.05) gives

$$\text{var}(x_{50}) = 0.1901, \quad \text{s.e.}(x_{50}) = \sqrt{0.1901} = 0.436$$

Thus, approximate 95% fiducial limits for the 50% point are 25.83 and 27.57 cm. (It would normally be quite sufficient to quote these as 25.8 and 27.6 cm respectively).

Had the value of X^2 been significantly large it would have been necessary to multiply the expression given in (II.05) by the factor X^2/f to give $\text{var}(x_{50})$. In this situation, when setting fiducial limits, the standard error should be multiplied by the value of Student's t for f degrees of freedom and not by the appropriate normal deviate (e.g. 1.96 for 95% limits).

When adopting this method of fitting selection curves it will often be found necessary to ignore data giving percentages less than 10% and greater than 90%, since the tail regions, especially the lower one, of selection curves often show very irregular fluctuations and systematic deviations from a logistic curve pattern.

2. Comparison of Methods of Fitting Selection Curves

On the assumption that the logistic is an appropriate specification for a selection curve, the method of fitting by maximum likelihood described in the previous section yields the most efficient estimates of the parameters of the curve. In particular the 50% point is most efficiently estimated by this method. Other methods, such as the method of moving averages, yield less efficient estimates. However, the slightly additional computational labour of the maximum likelihood method over other methods and the need for tables of logits and weighting coefficients detracts somewhat from its use, and the employment of simpler methods is further enhanced if they yield estimates close to those given by the maximum likelihood method.

Tables II.3 and II.4 show the results of a comparison of the estimates of the 50% points of fifteen actual selection curves provided by (a) the logistic curve fitted by maximum likelihood, (b) the moving average method and (c) the fitting of an ordinary least squares regression line to the observed proportions retained over approximately the 25%–75% range (over which part the selection curve is approximately linear). It is clear from Table II.4 that for these sets of data both the moving average method and the regression method give estimates of the 50% points, with no evidence of bias, close to those given by maximum likelihood. The estimated variances of the 50% points given in Table II.5 show, however, quite large discrepancies in several cases. This is to be expected since the simpler methods ignore the need for a differential weighting of the observations.

These results suggest that where only the 50% point is to be estimated, either the method of moving averages or simple linear regression over the central part of the curve (25%–75% range approximately) will give quite satisfactory results. The moving average method should not be used for estimating points other than the 50% point and the regression method is not satisfactory for points near the limit or beyond the 25% – 75% range. When the whole curve is to be estimated and where variances of the 50% (and other) points are required, there is no satisfactory alternative to the maximum likelihood method.

3. The Combination of Estimates

The combination of a set of selection factors into a single average figure was briefly considered in Section 8.2. Here the matter is discussed in greater detail.

Suppose that $x_1, x_2, \ldots, x_k$ are k estimates of the selection factor for a particular cod-end material and species obtained either within the framework of a single experiment or from several separate experiments, and let the true variances of these estimates be $\sigma_1^2, \sigma_2^2, \ldots, \sigma_k^2$. If logistic selection curves have been fitted by maximum likelihood and if the values of X^2 are not significant, the variances given by (II.05) may be taken as equal to $\sigma_1^2, \sigma_2^2, \ldots \sigma_k^2$.

However, if the values of X^2 are significant the variances of $x_1, x_2, \ldots x_k$, which we now denote as $s_1^2, s_2^2, \ldots, s_k^2$, are given by (II.05) multiplied by X^2/f and have degrees of freedom $f_1, f_2, \ldots, f_k$.

Before combining the k estimates it is necessary to ascertain whether or not they are homogeneous. This may be done by calculating the quantity

$$Q = \sum_{i=1}^{k} w_i(x_i - \bar{x}_w)^2 \qquad \text{(II.06)}$$

where $\bar{x}_w = \sum w_i x_i / \sum w_i$, $w_i = \sigma_i^{-2}$

If the x_i are homogeneous, Q will be distributed as χ^2 with $(k - 1)$ degrees of freedom. If this χ^2 is not significant the best estimate of the true mean μ of the x_i is the weighted mean $\bar{x}_w$ defined above. Its variance is given by

$$\text{var}(\bar{x}_w) = 1/\sum w_i$$

If the true variances are not known, that is if we only know $s_1^2, s_2^2 \ldots, s_k^2$, homogeneity may be tested by calculating

$$Q' = \sum w_i'(x_i - \bar{x}_{w'})^2 \qquad \text{(II.07)}$$

where $\bar{x}_{w'} = \sum w_i' x_i / \sum w_i'$, $w_i' = s_i^{-2}$

However, Q' is only approximately distributed as χ^2 and, where the degrees of freedom of the f_i are small, as will usually be the case, a more appropriate test is that due to Welch (1951). This requires the calculation of the quantity

$$\frac{Q'}{(k-1) + 2(k-2)a/(k+1)} \qquad \text{(II.08)}$$

where $a = \sum_{i=1}^{k} (1 - \frac{w_i'}{w'})/f_i$, $w' = \sum_{i=1}^{k} w_i'$

For small values of f_i this quantity is closely distributed according to the F-distribution with $(k - 1)$ and $(k^2 - 1)/3a$ degrees of freedom. If no heterogeneity is indicated by this test a weighted mean

$$\bar{x}_{w'} = \sum w_i' x_i / \sum w_i'$$

might be employed. Alternatively the weights w_i' might be replaced by weights

$$w_i'' = \frac{f_i - 2}{f_i s_i^2}$$

giving the weighted mean $\bar{x}_{w''}$.

These latter weights are unbiased estimates of $1/\sigma_i^2$, the "true" weights. The variances of these means are approximately

$$\text{var}(\bar{x}_{w'}) = \frac{1}{w'}\left\{1 + \frac{4}{w'}2\sum\frac{1}{f_i}w_i'(w' - w_i')\right\}$$

and $$\text{var}(\bar{x}_{w''}) = (1 + 2/\bar{f})/w''$$

where $$\bar{f} = \frac{1}{k}\sum f_i \text{ and } w'' = \sum w_i''$$

The former result is due to Meier (1953).

Experience with the fitting of selection curves has shown that the estimates $x_1, x_2, \ldots, x_k$ will frequently be non-homogeneous. Whatever the cause of these differences it will usually be necessary to form some combined estimate and a choice has to be made between using an unweighted mean or some sort of weighted mean. If μ is the overall mean to be estimated, each x_i may be written as

$$x_i = \mu + (\mu_i - \mu) + \varepsilon_i$$

and $\text{var}(x_i) = \sigma^2 + \sigma_i^2$ where σ^2 is the variance of the μ_i's about μ. If the true values of σ^2 and σ_i^2 were known a suitable weighted mean would be given by

$$\bar{x}_w = \sum W_i x_i / \sum W_i$$

with $W_i = 1/(\sigma^2 + \sigma_i^2)$.

If the σ_i^2 are small compared with σ^2 this estimate is closed to the unweighted mean

$$\bar{x} = \sum x_i/k$$

which has variance given by

$$\text{var}(\bar{x}) = (\sigma^2 + \bar{\sigma}^2)/k$$

where $\bar{\sigma}^2 = \sum\bar{\sigma}_i^2/k$.

In most situations δ^2 will be unknown but the quantity $\sum(x_i - \bar{x})^2/k - 1$ provides an unbiased estimate of $\sigma^2 + \bar{\sigma}^2$.

If the σ_i^2 (or the s_i^2 if the σ_i^2 are not known) are very variable and comparable in magnitude to σ^2, the sample semi-weighted mean $\bar{x}_W$ will probably be more precise than the unweighted mean $\bar{x}$. In this case estimated weights

$$W_i' = 1/(s^2 + \sigma_i^2) \text{ or } W_i'' = 1/(s^2 + s_i^2)$$

should be employed. The variance component s^2 should be estimated from the relationship

$$s^2 = \frac{1}{k-1}\sum(x_i - \bar{x})^2 - \bar{s}^2$$

where $\bar{s}^2 = \sum s_i^2/k$.

As an example, consider the results shown in Table II.5. In column (1) are given the estimated 50% points for selection curves obtained from catches of whiting in eight sets of hauls

with Terylene cod-ends, using the covered cod-end method. The hauls in each set were pooled in order to provide sufficient data to allow logistic curves to be fitted by maximum likelihood. The various sets of hauls were made in the same area but were taken over a period of several months.

The average cod-end mesh sizes used on each occasion are given in column (2).

In column (3) the values of X^2 are shown, together with their degrees of freedom. The value of X^2 for set 2 is on the borderline of significance due to a large contribution associated with one slightly aberrant value based on a large number of fish. The suggestion of heterogeneity for this set has, quite reasonably, been ignored.

The variances of the estimated 50% points, as given by expression (II.05), are shown in column (4).

The 50% points cannot be combined since they relate to cod-ends of different mesh size. It is, however, reasonable to combine the selection factors obtained by dividing the figures in column (1) by those in column (2). These are given in column (5) and their variances, obtained from those in column (4) by division by the mesh size, in column (6).

The estimates x_i in column (5) are very clearly not homogeneous. (The minimum difference between these estimates, 0.18 is more than three times its standard error). The value of $\chi^2 = \sum \bar{\sigma}_i^2 (x_i - \bar{x}_w)^2$ is actually 1035.26 which is highly significant. This quantity is obtained from the figures in columns (7) and (8). The choice of a combined estimate lies therefore between the unweighted mean and the sample semi-weighted mean.

The variance component σ^2 is estimated from the quantity $\sum (x - \bar{x})^2/7 = 0.260629$, this being an estimate of $\sigma^2 + \bar{\sigma}^2$ where $\bar{\sigma}^2$ is the mean of the figures in column (6), viz. 0.002531. Since σ^2 is clearly very much greater than any of the individual values of σ_i^2, an unweighted mean is quite appropriate here.

Thus the combined estimate is $\bar{x} = 4.23$ with $\text{var}(\bar{x}) = 0.260629/8 = 0.0326$.

This example illustrates the most typical situation occurring in the combination of estimated selection factors and bears out the statement made in Section 8.1 that an unweighted mean is, in general, the most appropriate single estimate.

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TABLE I

Working Sheet showing Selection Data for Haddock from Covered Cod-end Experiment

(1) Length (cm)	(2) No. of fish in cod-end	(3) No. of fish in cover	(4) Percentage retained
18	0	186	0
19	6	194	3
20	9	140	6
21	17	66	20
22	8	19	30
23	12	10	55
24	20	5	80
25	16	2	89
26	11	1	92
27	7	0	100

TABLE II

Working Sheet showing Data for Haddock from Alternate Haul Experiment

Length (cm)	(A) No. of fish in 35 mm cod-end	(B) No. of fish in 87 mm cod-end	(C) B/A		(D) $B/1.28A$
24	1	-	0.00		0.00
25	1	-	0.00		0.00
26	3	-	0.00		0.00
27	14	1	0.07		0.05
28	30	5	0.17		0.13
29	49	19	0.39		0.30
30	60	29	0.48		0.38
31	50	51	1.02		0.80
32	70	91	1.30		1.02
33	108	120	1.11		0.87
34	88	118	1.34		1.05
35	84	107	1.27	av. = 1.28	1.00
36	68	78	1.15		0.90
37	37	52	1.41		1.10
38	33	40	1.21		0.95
39	12	17	1.42		1.11
40	5	17	3.40		
41	6	14	2.33		
42	10	10	1.00		
43	1	4	4.00		
44	6	6	1.00		
45	2	2	1.00		
46	1	5	5.00		
47	-	1	-		
	$\sum_{32}^{47} A = 531$	$\sum_{32}^{47} B = 682$	$682/531 = 1.28$		

TABLE II.1

Maximum Likelihood Fitting of Logistic Selection Curve

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
x	n	r	p	Emp. Log	L	P	w	nw	nwx	nP
23.5	75	15	0.20	-0.69	-0.82	0.162	0.5444	40.830	959.505	12.15
25.5	20	6	0.30	-0.42	-0.32	0.345	0.9038	18.076	460.938	6.90
27.5	25	14	0.56	0.12	0.19	0.594	0.9646	24.115	663.162	14.85
29.5	19	16	0.84	0.83	0.70	0.802	0.6347	12.059	355.740	15.24
31.5	12	11	0.92	1.22	1.20	0.917	0.3050	3.660	115.290	11.00

$\sum nw = 98.740 = A$ $\qquad$ $\sum np = 62 = E$

$\sum nwx = 2554.635 = B$ $\qquad$ $\sum nP = 60.14 = F$

$\sum nwx^2 = 66665.2065 = C$ $\qquad$ $E - F = 1.86 = G$

$B^2/A = 66094.3891 = D$ $\qquad$ $\sum nxp = 1709.080 = H$

$S(nwx^2) = C - D = 570.8174$ $\qquad$ $\sum nxP = 1665.930 = I$

$H - I = 43.150 = J$

$$\Delta b_1 = (J - GB/A) \div S(nwx^2)$$

$$= (43.15 - 48.12) \div 570.8174$$

$$= -0.0087$$

$$\Delta a_1 = G/A - (\Delta b_1) B/A$$

$$= 0.0188 + 0.2251$$

$$= 0.2439$$

TABLE II.2

Calculation of Test of Goodness of Fit

x	n	L_1	P_1	Q_1	nP_1	r	$\frac{(r - nP_1)^2}{nP_1Q_1}$
23.5	75	-0.781	0.17	0.83	12.8	15	0.456
25.5	20	-0.293	0.36	0.64	7.2	6	0.312
27.5	25	0.194	0.60	0.40	15.0	14	0.167
29.5	19	0.682	0.80	0.20	15.2	16	0.211
31.5	12	1.170	0.91	0.09	10.9	11	0.010
							$X^2 = 1.156$

TABLE II.3

Comparison of 50% Points obtained by Different Methods of Estimation

Maximum Likelihood	Moving Averages	Linear Regression
24.6	24.5	24.5
26.5	26.6	26.5
25.5	25.7	25.6
21.9	20.7	21.7
23.0	23.0	23.0
25.5	25.7	25.4
18.2	18.2	18.2
21.7	21.6	21.7
27.5	27.5	27.5
22.0	21.8	22.1
25.6	25.6	25.6
24.7	24.5	24.4
28.2	28.5	28.2
31.2	31.1	31.1
32.9	32.5	32.6

TABLE II.4

Comparison of Variances of 50% Points obtained by Different Methods of Estimation

Maximum Likelihood	Moving Averages	Linear Regression
0.0395	0.0371	0.0757
0.0530	0.0645	0.0350
0.2707	0.0557	0.3922
0.1377	0.6999	0.9239
0.0905	0.1713	0.0182
0.1810	0.4199	0.3094
0.0046	0.0053	0.0038
0.0134	0.0161	0.0045
0.0629	0.0784	0.0471
0.1423	0.2515	0.0319
0.0533	0.0593	0.1166
0.1469	0.2356	0.5138
0.0776	0.0876	0.0708
0.2154	0.1970	0.0182
0.0453	0.0305	0.0759

TABLE II.5

Combination of Estimates
Test for Homogeneity of Selection Factors

Set	x_{50}	Mesh Size (cm)	χ^2 (d.f.)	Var. (x_{50})	S.F. (x_i)	Var. (x_i) $10^6.\sigma_i^2$	$w_i = 1/\sigma_i^2$	$w_i x_i$
1	25.4	6.0	7.60 (4)	0.1549	4.23	2582	387	1637.01
2	23.3	6.3	11.42 (5)	0.1139	3.70	1808	553	2046.10
3	27.0	7.2	1.88 (3)	0.2896	3.75	4022	249	933.75
4	21.1	6.0	11.96 (6)	0.0573	3.52	955	1047	3685.44
5	34.9	7.2	3.77 (3)	0.2138	4.85	2969	337	1634.45
6	33.3	7.2	10.74 (6)	0.2696	4.62	3744	267	1233.54
7	32.7	7.2	4.49 (6)	0.2055	4.54	2854	350	1589.00
8	33.5	7.2	7.96 (4)	0.0945	4.65	1312	762	3543.30

$$Q = \sum w_i x_i^2 - (\sum w_i x_i)^2 / \sum w_i = 68285.88 - 67250.62$$
$$= 1035.26$$

$$\sum (x_i - \bar{x})^2 / 7 = 0.260629$$

TABLE II.6

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LOGITS

The Logit or r, z Transformation

p%	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
50	·0000	·0020	·0040	·0060	·0080	·0100	·0120	·0140	·0160	·0180
51	·0200	·0220	·0240	·0260	·0280	·0300	·0320	·0340	·0360	·0380
52	·0400	·0420	·0440	·0460	·0480	·0500	·0520	·0541	·0561	·0581
53	·0601	·0621	·0641	·0661	·0681	·0701	·0721	·0741	·0761	·0782
54	·0802	·0822	·0842	·0862	·0882	·0902	·0923	·0943	·0963	·0983
55	·1003	·1024	·1044	·1064	·1084	·1104	·1125	·1145	·1165	·1186
56	·1206	·1226	·1246	·1267	·1287	·1307	·1328	·1348	·1368	·1389
57	·1409	·1430	·1450	·1471	·1491	·1511	·1532	·1552	·1573	·1593
58	·1614	·1634	·1655	·1676	·1696	·1717	·1737	·1758	·1779	·1799
59	·1820	·1841	·1861	·1882	·1903	·1923	·1944	·1965	·1986	·2007
60	·2027	·2048	·2069	·2090	·2111	·2132	·2153	·2174	·2195	·2216
61	·2237	·2258	·2279	·2300	·2321	·2342	·2363	·2384	·2405	·2427
62	·2448	·2469	·2490	·2512	·2533	·2554	·2575	·2597	·2618	·2640
63	·2661	·2683	·2704	·2726	·2747	·2769	·2790	·2812	·2833	·2855
64	·2877	·2899	·2920	·2942	·2964	·2986	·3008	·3029	·3051	·3073
65	·3095	·3117	·3139	·3161	·3183	·3205	·3228	·3250	·3272	·3294
66	·3316	·3339	·3361	·3383	·3406	·3428	·3451	·3473	·3496	·3518
67	·3541	·3564	·3586	·3609	·3632	·3654	·3677	·3700	·3723	·3746
68	·3769	·3792	·3815	·3838	·3861	·3884	·3907	·3931	·3954	·3977
69	·4001	·4024	·4047	·4071	·4094	·4118	·4142	·4165	·4189	·4213
70	·4236	·4260	·4284	·4308	·4332	·4356	·4380	·4404	·4428	·4453
71	·4477	·4501	·4526	·4550	·4574	·4599	·4624	·4648	·4673	·4698
72	·4722	·4747	·4772	·4797	·4822	·4847	·4872	·4897	·4922	·4948
73	·4973	·4999	·5024	·5049	·5075	·5101	·5126	·5152	·5178	·5204
74	·5230	·5256	·5282	·5308	·5334	·5361	·5387	·5413	·5440	·5466
75	·5493	·5520	·5547	·5573	·5600	·5627	·5654	·5682	·5709	·5736
76	·5763	·5791	·5818	·5846	·5874	·5901	·5929	·5957	·5985	·6013
77	·6042	·6070	·6098	·6127	·6155	·6184	·6213	·6241	·6270	·6299
78	·6328	·6358	·6387	·6416	·6446	·6475	·6505	·6535	·6565	·6595
79	·6625	·6655	·6685	·6716	·6746	·6777	·6807	·6838	·6869	·6900
80	·6931	·6963	·6994	·7026	·7057	·7089	·7121	·7153	·7185	·7218
81	·7250	·7283	·7315	·7348	·7381	·7414	·7447	·7481	·7514	·7548
82	·7582	·7616	·7650	·7684	·7718	·7753	·7788	·7823	·7858	·7893
83	·7928	·7964	·7999	·8035	·8071	·8107	·8144	·8180	·8217	·8254
84	·8291	·8328	·8366	·8404	·8441	·8480	·8518	·8556	·8595	·8634
85	·8673	·8712	·8752	·8792	·8832	·8872	·8912	·8953	·8994	·9035
86	·9076	·9118	·9160	·9202	·9245	·9287	·9330	·9373	·9417	·9461
87	·9505	·9549	·9594	·9639	·9684	·9730	·9775	·9822	·9868	·9915
88	·9962	1·0010	1·0058	1·0106	1·0154	1·0203	1·0253	1·0302	1·0352	1·0403
89	1·0454	1·0505	1·0557	1·0609	1·0661	1·0714	1·0768	1·0822	1·0876	1·0931
90	1·0986	1·1042	1·1098	1·1155	1·1212	1·1270	1·1329	1·1388	1·1447	1·1507
91	1·1568	1·1630	1·1692	1·1754	1·1817	1·1881	1·1946	1·2011	1·2077	1·2144
92	1·2212	1·2280	1·2349	1·2419	1·2490	1·2562	1·2634	1·2707	1·2782	1·2857
93	1·2933	1·3011	1·3089	1·3169	1·3249	1·3331	1·3414	1·3498	1·3583	1·3670
94	1·3758	1·3847	1·3938	1·4030	1·4124	1·4219	1·4316	1·4415	1·4516	1·4618
95	1·4722	1·4828	1·4937	1·5047	1·5160	1·5275	1·5393	1·5513	1·5636	1·5762
96	1·5890	1·6022	1·6157	1·6296	1·6438	1·6584	1·6734	1·6888	1·7047	1·7211
97	1·7380	1·7555	1·7736	1·7923	1·8117	1·8318	1·8527	1·8745	1·8972	1·9210
98	1·9459	1·9721	1·9996	2·0287	2·0595	2·0923	2·1273	2·1649	2·2054	2·2494
99	2·2976	2·3507	2·4101	2·4774	2·5550	2·6467	2·7587	2·9031	3·1063	3·4534

The logit transformation, $z = \frac{1}{2}\log_e(p/q)$, is equivalent to the r, z transformation with $r = 2p-1$ (see Table VIIi). For values of $p < 0{\cdot}5$ logits are *negative*, and numerically equal to the tabular values for $1-p$.

TABLE II.7

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L O G I T S

Weighting Coefficients and Logit Values to be used for Final Adjustments

Expected value	Working values Minimum	Range	Maximum	Weighting coefficient	Expected value	Working values Minimum	Range	Maximum	Weighting coefficient
0·00	−1·0000	2·0000	1·0000	1·00000	2·00	−25·799	28·308	2·5092	·070651
0·05	−1·0026	2·0050	1·0024	·99750	2·05	−28·620	31·178	2·5583	·064147
0·10	−1·0107	2·0201	1·0094	·99007	2·10	−31·743	34·351	2·6075	·058223
0·15	−1·0249	2·0453	1·0204	·97783	2·15	−35·200	37·857	2·6568	·052831
0·20	−1·0459	2·0811	1·0352	·96104	2·20	−39·025	41·732	2·7061	·047925
0·25	−1·0744	2·1277	1·0533	·94001	2·25	−43·259	46·014	2·7556	·043465
0·30	−1·1111	2·1855	1·0744	·91514	2·30	−47·942	50·747	2·8050	·039411
0·35	−1·1569	2·2552	1·0983	·88685	2·35	−53·124	55·978	2·8545	·035728
0·40	−1·2128	2·3375	1·1247	·85564	2·40	−58·855	61·759	2·9041	·032384
0·45	−1·2798	2·4331	1·1533	·82200	2·45	−65·195	68·149	2·9537	·029348
0·50	−1·3591	2·5430	1·1839	·78645	2·50	−72·207	75·210	3·0034	·026592
0·55	−1·4521	2·6685	1·2164	·74948	2·55	−79·961	83·014	3·0530	·024092
0·60	−1·5601	2·8107	1·2506	·71158	2·60	−88·536	91·639	3·1028	·021825
0·65	−1·6846	2·9709	1·2863	·67319	2·65	−98·018	101·17	3·1525	·019769
0·70	−1·8276	3·1509	1·3233	·63474	2·70	−108·50	111·71	3·2023	·017904
0·75	−1·9908	3·3524	1·3616	·59659	2·75	−120·10	123·35	3·2520	·016214
0·80	−2·1765	3·5774	1·4009	·55906	2·80	−132·91	136·22	3·3018	·014683
0·85	−2·3870	3·8283	1·4413	·52242	2·85	−147·08	150·44	3·3517	·013295
0·90	−2·6248	4·1074	1·4826	·48692	2·90	−162·75	166·15	3·4015	·012037
0·95	−2·8929	4·4177	1·5248	·45272	2·95	−180·07	183·52	3·4514	·010898
1·00	−3·1945	4·7622	1·5677	·41997	3·00	−199·21	202·72	3·5012	·0098660
1·05	−3·5331	5·1443	1·6112	·38878	3·05	−220·38	223·93	3·5511	·0089314
1·10	−3·9125	5·5679	1·6554	·35920	3·10	−243·77	247·38	3·6010	·0080849
1·15	−4·3371	6·0372	1·7001	·33128	3·15	−269·64	273·29	3·6509	·0073183
1·20	−4·8116	6·5570	1·7454	·30502	3·20	−298·22	301·92	3·7008	·0066242
1·25	−5·3412	7·1322	1·7910	·28041	3·25	−329·82	333·57	3·7508	·0059957
1·30	−5·9319	7·7690	1·8371	·25743	3·30	−364·75	368·55	3·8007	·0054267
1·35	−6·5899	8·4735	1·8836	·23603	3·35	−403·35	407·20	3·8506	·0049115
1·40	−7·3223	9·2527	1·9304	·21615	3·40	−446·02	449·92	3·9006	·0044452
1·45	−8·1371	10·115	1·9775	·19773	3·45	−493·19	497·14	3·9505	·0040230
1·50	−9·0428	11·068	2·0249	·18071	3·50	−545·32	549·32	4·0005	·0036409
1·55	−10·049	12·121	2·0725	·16500	3·55	−602·93	606·98	4·0504	·0032950
1·60	−11·166	13·287	2·1204	·15053	3·60	−666·62	670·72	4·1004	·0029819
1·65	−12·406	14·575	2·1684	·13722	3·65	−737·00	741·15	4·1503	·0026985
1·70	−13·782	15·999	2·2167	·12501	3·70	−814·79	818·99	4·2003	·0024420
1·75	−15·308	17·573	2·2651	·11381	3·75	−900·77	905·02	4·2503	·0022099
1·80	−16·999	19·313	2·3137	·10356	3·80	−995·80	1000·1	4·3003	·0019998
1·85	−18·874	21·236	2·3624	·094180	3·85	−1100·8	1105·2	4·3502	·0018097
1·90	−20·951	23·362	2·4112	·085610	3·90	−1216·9	1221·3	4·4002	·0016376
1·95	−23·251	25·711	2·4601	·077787	3·95	−1345·2	1349·6	4·4502	·0014819

Table XI1 is used in the same manner as the probit table for final adjustments (Table IX2), the working value being given by q Min. Value$+p$ Max. Value, Min. Value$+p$ Range, or Max. Value$-q$ Range. If the expected value is negative interchange the tabular minimum and maximum values with change of sign. Thus with an expected value of $-0{\cdot}65$ and $p = 0{\cdot}3$ the working value is $0{\cdot}7(-1{\cdot}2863)+0{\cdot}3(1{\cdot}6846) = -0{\cdot}3950$.

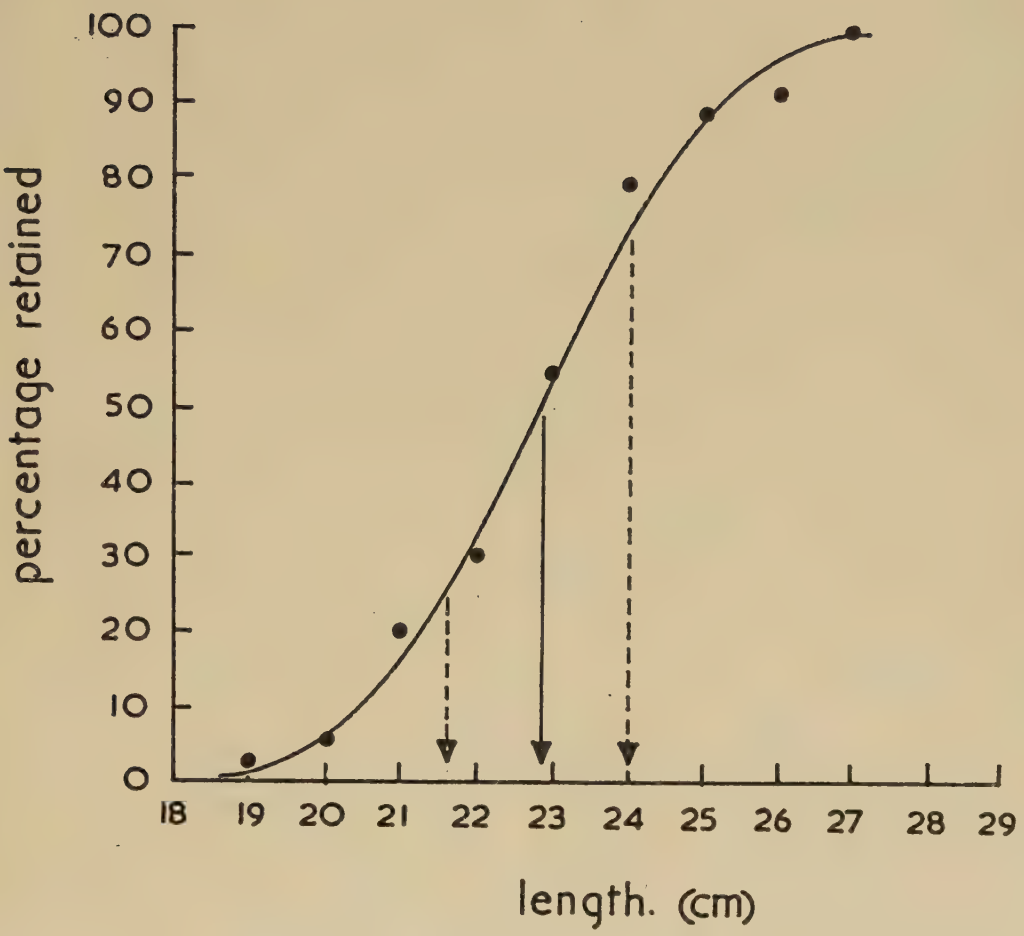


Fig. 1 Mesh selection curve for haddock
(Data from Table I)

FIG. 2(a)

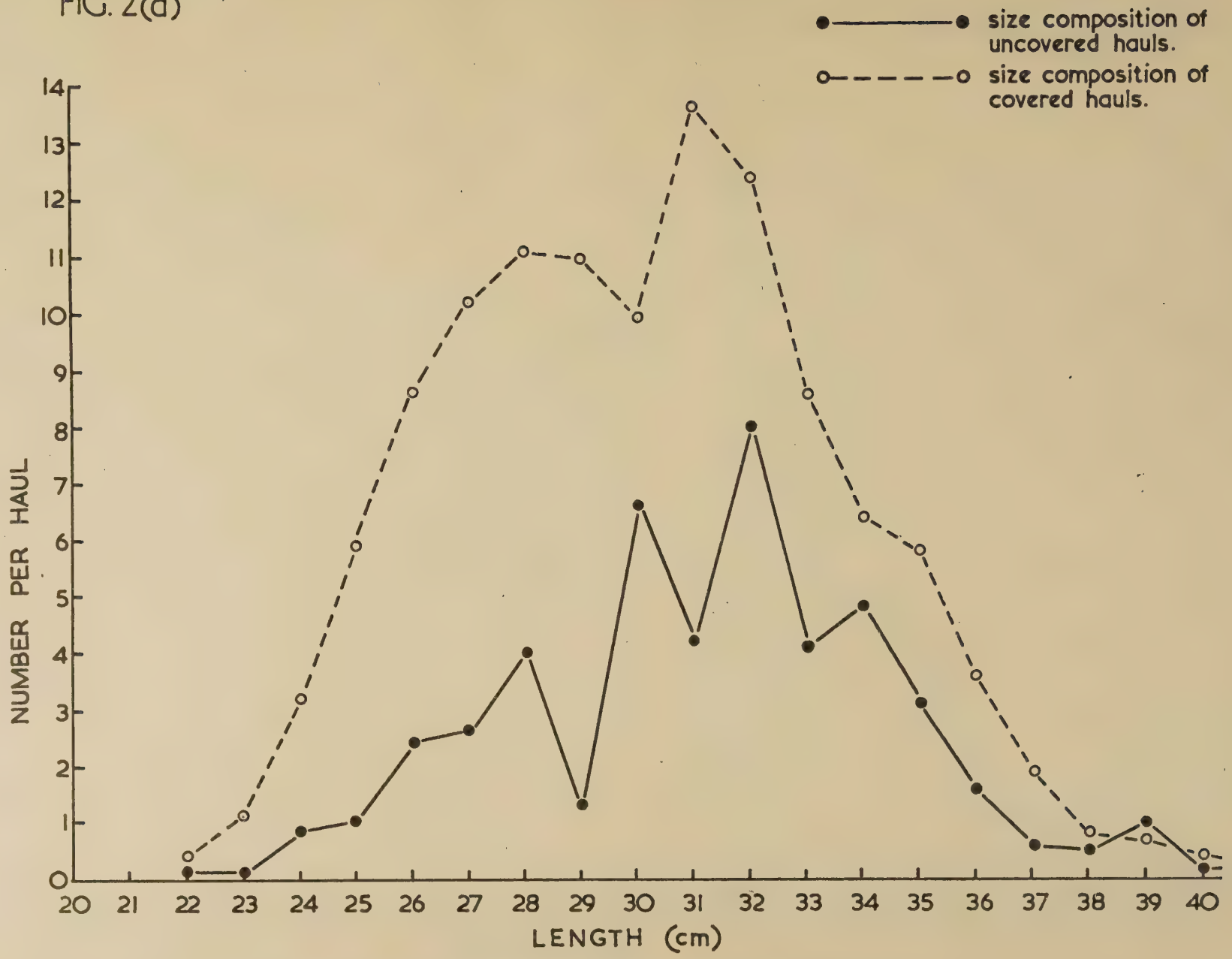


Fig. 2a Length composition of catches of whiting by covered and uncovered cod-ends, expressed as numbers per haul

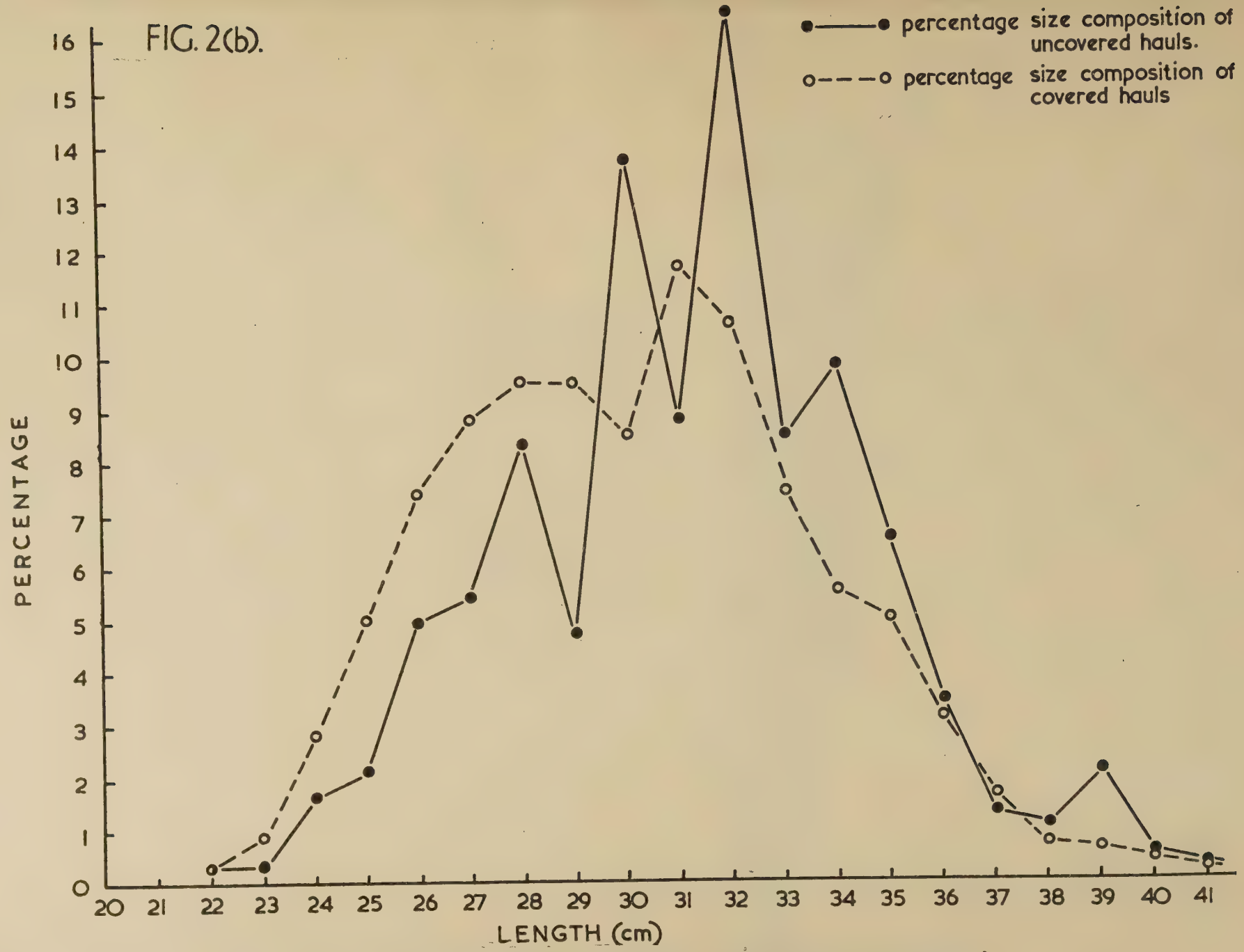


Fig. 2b Length composition of catches of whiting by covered and uncovered cod-end, expressed as percentages

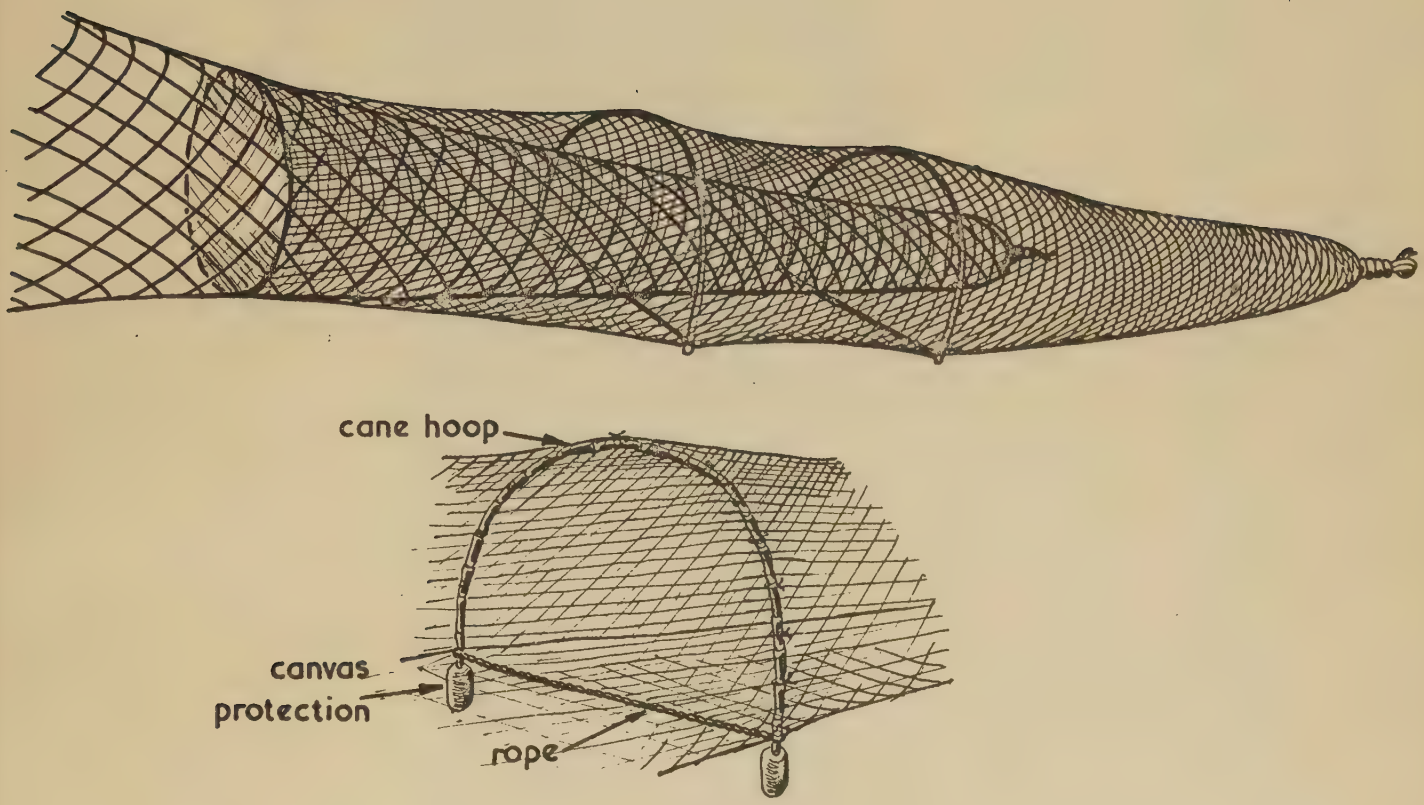


Fig. 3 Diagram of rigging of whole cod-end cover with cane hoops

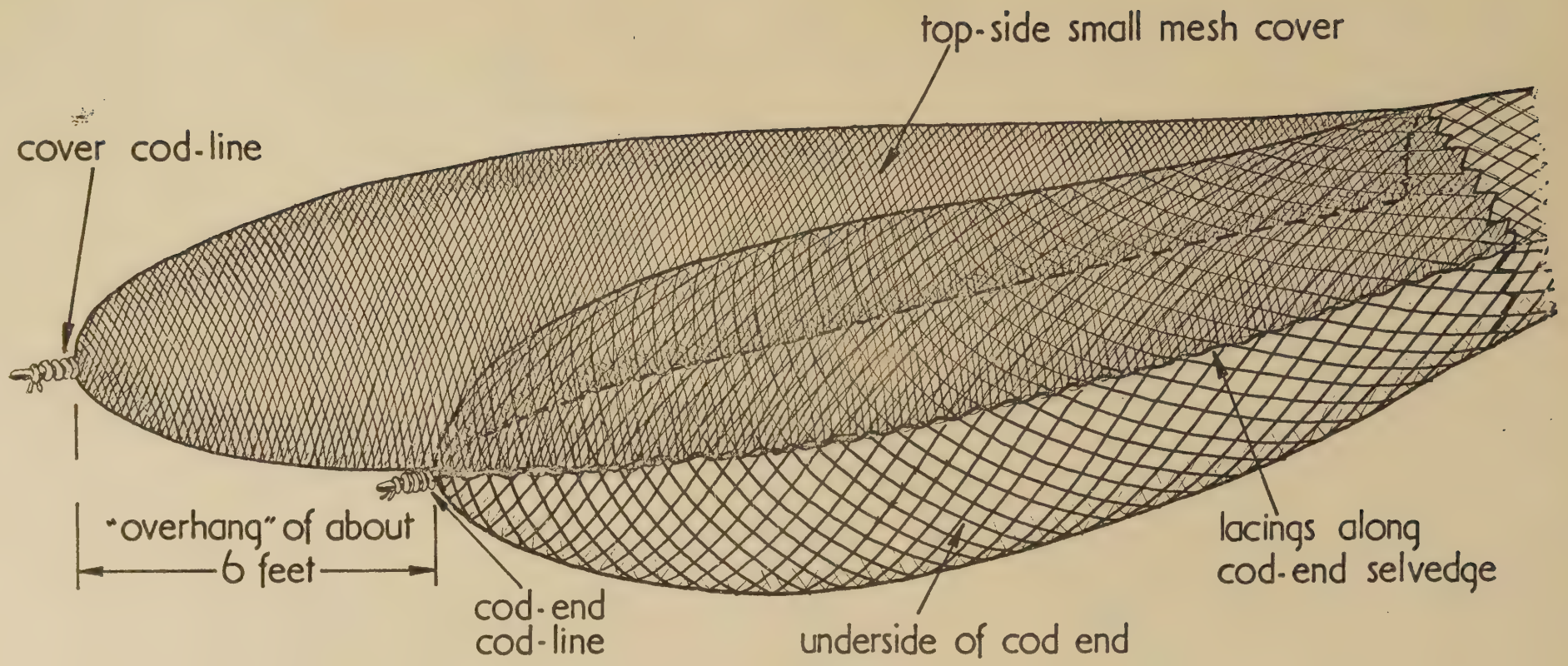


Fig. 4 General view of cod-end top-side cover, showing essential ancillary rigging of cod-end

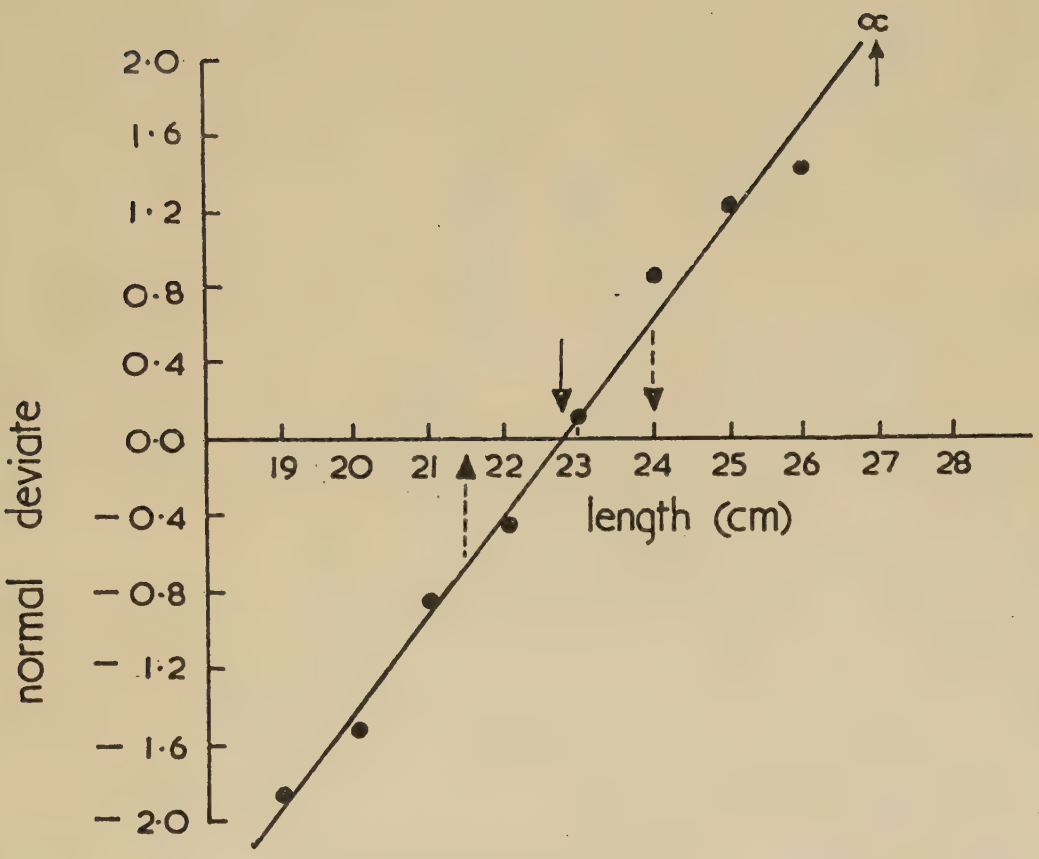


Fig. 5 Transformed selection curve for haddock

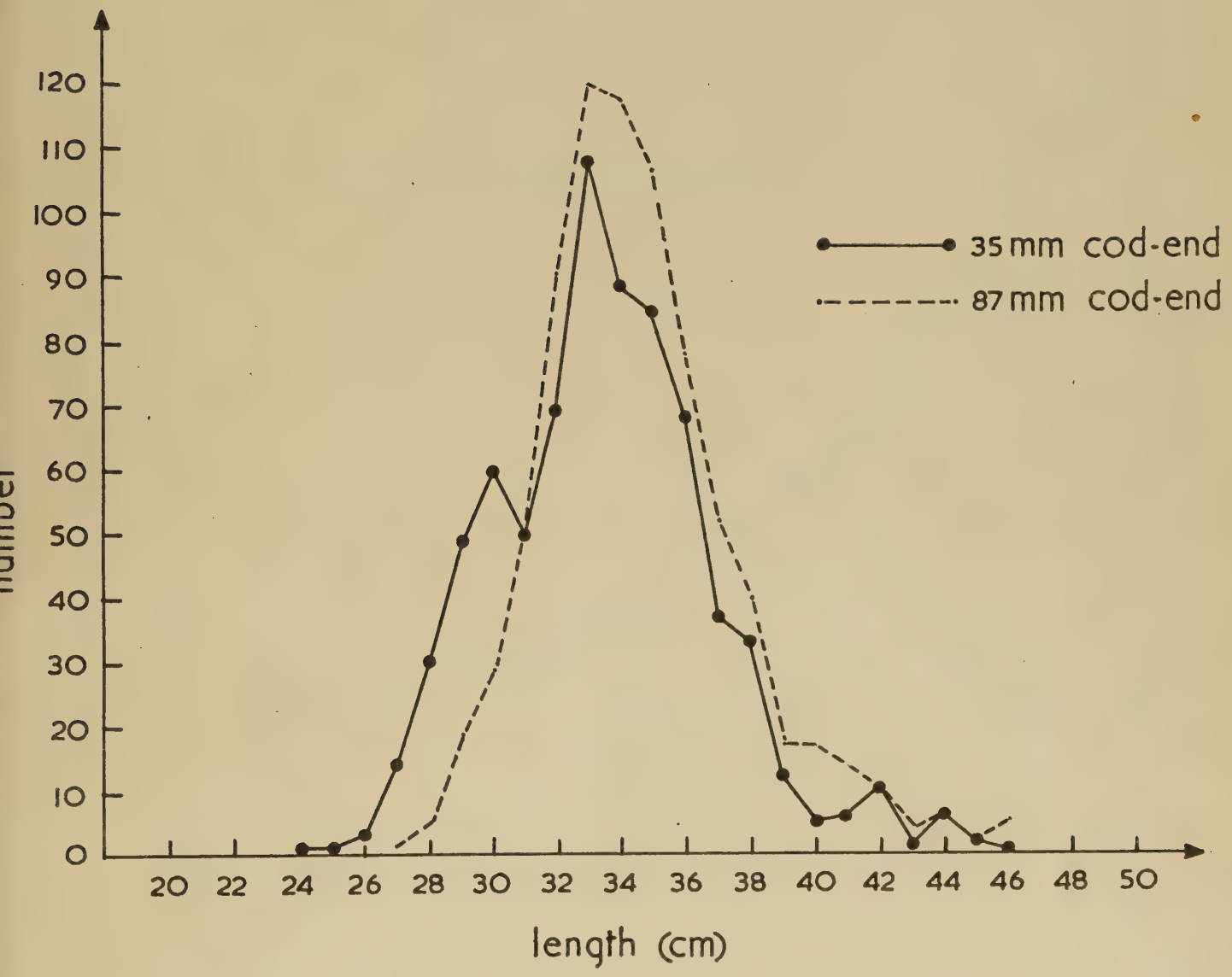


Fig. 6a Length composition of small and large mesh catches of haddock

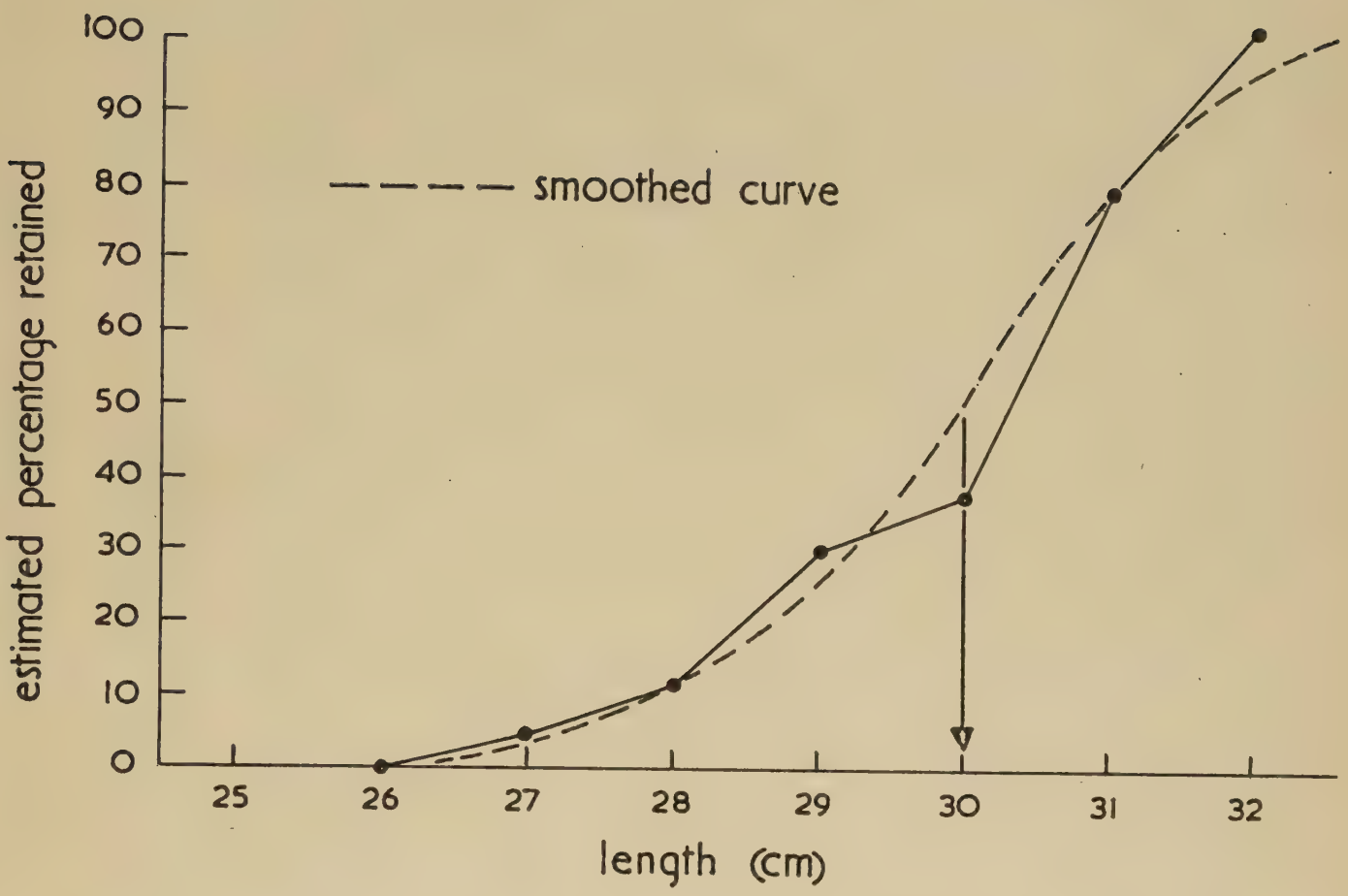


Fig. 6b Haddock selection curve for polypropylene 87 mm cod-end

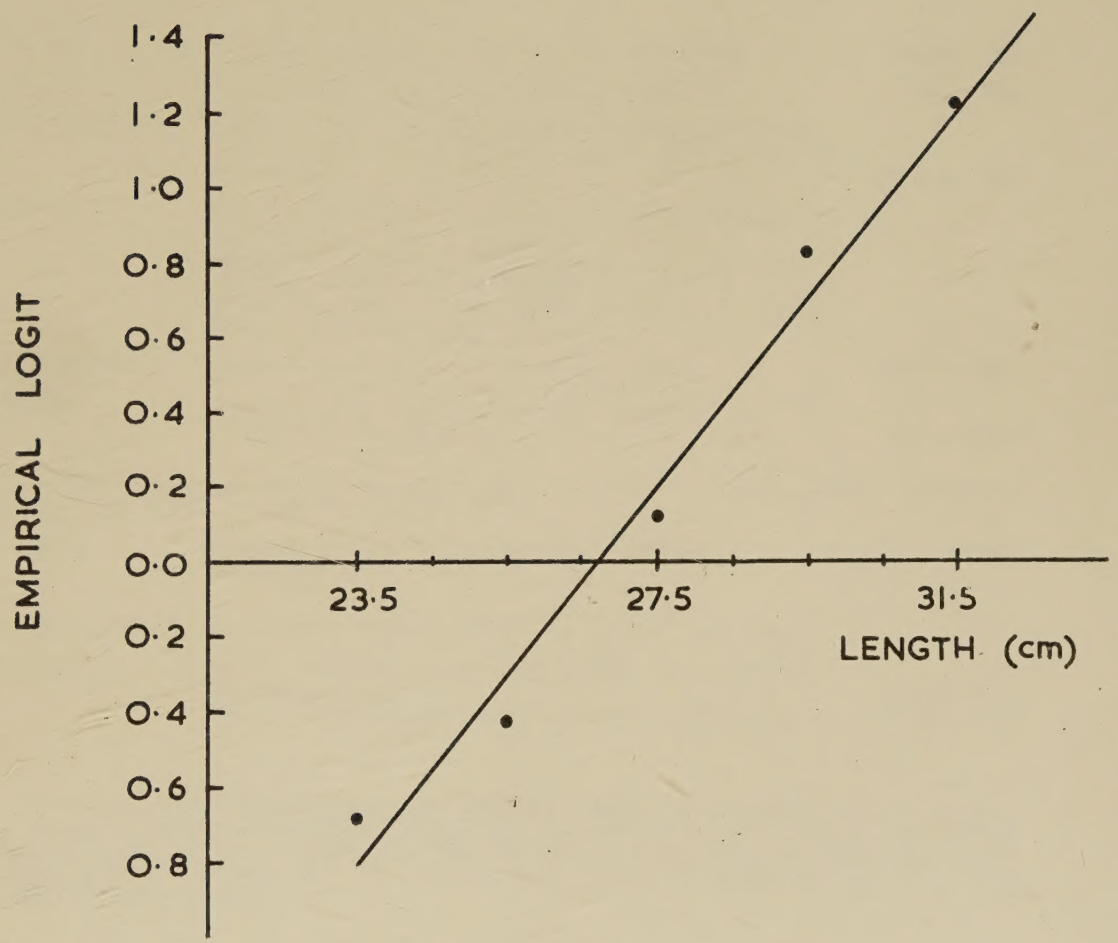
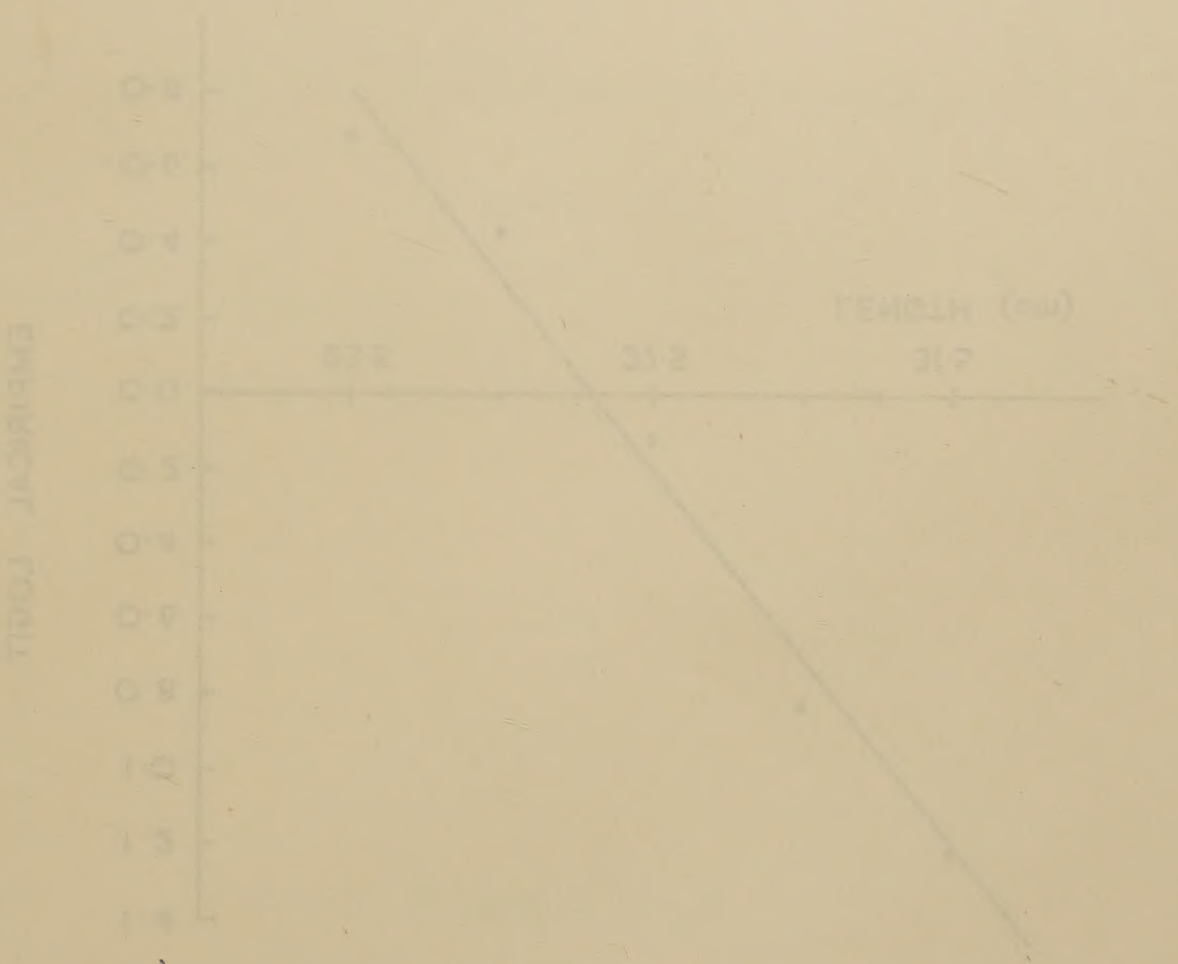


Fig. II.1 Fitting of logistic selection curve



FAO FISHERIES TECHNICAL PAPER (MFS)

Documents in this group are provisional editions of volumes or sections of FAO MANUALS IN FISHERIES SCIENCE, usually in the language of the original draft. They are given a limited distribution for comment by collaborators in this project, and for use of FAO headquarters and field staff and at training centres, courses and seminars. Revised versions are subsequently published by FAO in the official languages of the Organization. Further information and extra copies can be obtained from:

Biological Data Section
Fish Stock Evaluation Branch
Fishery Resources and Exploitation Division
FAO, Rome, ITALY

FB/T26	Manual of Sampling Methods for Fisheries Biology	October 1962
FIb/T38	Tables of Yield Functions for Fishery Assessment	June 1964
FIb/T26 Suppl. 1	Manual of Sampling and Statistical Methods for Fisheries Biology. Part. II - Statistical Methods - Chapter No. 5 Computations	February 1965
FIb/T51	Manual of Methods for Fish Stock Assessment - Report on Marking Manuel sur les méthodes d'évaluation des stocks ichtyologiques - Rapport sur le marquage Manual de métodos para la evaluación de los stocks de peces - Informe sobre marcado	July 1965
FIb/T40 Rev. 1	Manual of Methods of Fish Population Analysis	November 1965
FIb/T41	Manual of Methods for Fish Stock Assessment. Part. III. Selectivity of Fishing Gear	January 1966

A printed English version of "Manual of Field Methods in Fisheries Biology. Provisional Edition" was issued in 1960, as a revision of:

FB/58/T1	A Manual of Field Methods in Fisheries Biology (Preliminary draft)	September 1958

Drafts of "Manual of Laboratory Methods in Fisheries Biology" were issued as:

FB/58/T3	Part I - Physical and Chemical Methods in Meteorology and Oceanography	January 1958
	Part II - Laboratory Methods on Plankton and Benthos	February 1958

Revised versions of these have been combined with the Field Methods Manual to produce a "Manual of Methods in Fisheries Biology", the definitive text of which will be published in three language versions as **FAO Man. Fish, Sci.** (1) (in preparation). A provisional English edition of **FAO Man. Fish. Sci.** (2) "Fisheries Science" was issued for FAO by CSIRO, Cronulla, Australia, in 1960.

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